FOR PUBLIC RELEASE

HONOLULU RAPID TRANSIT PROGRAM

TASK 4.04

HOTEL STREET SUBWAY STUDY REPORT

Prepared for

DEPARTMENT OF TRANSPORTATION SERVICES
OFFICE OF RAPID TRANSIT

City and County of Honolulu
Frank F. Fasi, Mayor

Prepared by

ICF KAISER ENGINEERS, INC.

July 1991

HONOLULU RAPID TRANSIT PROGRAM

TASK 4.04

HOTEL STREET SUBWAY STUDY REPORT

Prepared for

DEPARTMENT OF TRANSPORTATION SERVICES
OFFICE OF RAPID TRANSIT

City and County of Honolulu
Frank F. Fasi, Mayor

Prepared by

ICF KAISER ENGINEERS, INC.

July 1991

Preparation of this report was financially assisted with grants from the U.S. Department of Transportation under Sections 3 and 9 of the Urban Mass Transportation Act of 1964 as amended.

TABLE OF CONTENTS

FIGURES

1. EXECUTIVE SUMMARY

This document represents a summary of the planning, architectural, and engineering studies that were performed as a prelude to the preparation of the *Hotel Street Subway Design, Supply, And Construction Request for Proposals.*

The Hotel Street alignment was based on the alignment corridor documented in the *Alternative Analysis and Draft Environmental Impact Statement* (AA/DEIS), dated March 1990. The *Hotel Street Subway Study* report did not include further investigation of alternative alignments through the City of Honolulu. The selected alignment was evaluated in terms of existing, natural and man-made features located along the proposed route. The limited right-of-way along Hotel Street, the existing Nuuanu Stream bridge, and the geologic profile were identified as three major constraints governing the proposed horizontal and vertical geometry and the associated guideway configuration. Of particular significance is the narrow right-of-way along Hotel Street which is generally straddled by historic two- and three-story masonry buildings or modern high-rise buildings with multi-level underground structures. This condition has resulted in a guideway configuration below Hotel Street that is vertically stacked with Ewa-bound trains running above the Koko Head-bound trains.

The right-of-way constraint also influenced the general configuration of the Hotel/Bethel and Hotel/Alakea stations. Consistent with the guideway configuration, both stations have vertically stacked platforms with the Ewa-bound passenger platform located above the Koko Head-bound passenger platform. Beyond Hotel and Richards streets as the guideway alignment continues in the Koko Head direction, the right-of-way constraint diminishes. Consequently, the guideway arrangement transitions to a traditional side-by-side configuration. The last underground passenger station (Civic Center Station), located near the Municipal Building, is configured as a traditional center platform station with the guideway positioned in a parallel orientation on the same horizontal plane.

The geology encountered along the Hotel Street Subway alignment is mixed and highly complex when appraised from the perspective of underground construction. The major geological constituents include black cinders, coral reef deposits, alluvium, basalt, tuff and lagoon deposits. This environment is further complicated by the local ground water elevation, which is measured to be approximately 10 to 20 feet below the ground surface. These conditions will be a major consideration influencing the methods proposed for subway construction, and the final design characteristics of the permanent structure.

With the exception of basalt, all of the materials are considered to be relatively soft. The Honolulu series basalts, however, are extraordinarily hard and may reach unconfined compressive strengths of approximately 25,000 psi. Tunneling and excavation equipment is most efficiently designed and effectively utilized when it is operated in a homogenous environment. An analysis of the geologic profile revealed that the extremely hard basalts were found at minimum depths of -50 to -60 feet. In a conscientious effort to avoid a mixed face (hard versus soft) tunneling environment, the vertical alignment was established to avoid the regions consisting of basalt. By adhering to this objective it was rationalized that construction difficulties would be reduced with a corresponding savings in cost. However, the actual below grade conditions can never be predicted with exact precision, but only with a degree of certainty that is measured by the extent of the geotechnical investigative program. This publication is based on limited geotechnical data.

It is currently assumed that all of the construction will occur in relatively soft materials. The lagoon deposits found near the Nuuanu Stream are so soft that some form of ground improvement technique will probably be required, regardless of the selected construction method. Ground improvement techniques typically consist of jet grout or chemical grout; both serve to strengthen soil.

Ground displacement, settlement, and deflections are all of concern, particularly in soft soils along the highly developed Hotel Street alignment. It is imperative that the design and construction carefully consider and monitor potential ground displacements so as to mitigate the possibility of inflicting structural damage on adjacent sensitive buildings. As stated earlier, the geology is complex consisting of a non-homogenous mix of materials. The corals are interwoven with alluvial clays, silts and sandy gravels. The disjointed nature of this material will make the magnitude and profiles of any settlement troughs very difficult to predict.

The mitigation measures entail extensive geotechnical analysis, utilization of construction techniques that characteristically minimize ground displacement, and the implementation of a comprehensive monitoring program. These measures are applicable to mined and cut-and-cover construction methods, although each have particular advantages and disadvantages that are described in detail under Sections 5 and 6.

The ground water elevation is an additional concern during the construction period and service life of the transit facility. With the exception of isolated segments of surface penetrating structures, the entire subway is located below the water table. This has a particularly severe impact when construction is considered in light of the existing soil conditions. A high percentage of the soil is quite pervious, thus high volumes of ground water inflow can be expected along excavated or open surfaces which extend below the water table. Additionally, if water is permitted to flow freely into an excavation or mined tunnel, it is likely to carry fines or small particles of soil that constitute the natural state of the ground. Should a significant amount of fines be lost by ground water inflow, the supporting capacity of the immediate ground will be lost. The consequence could be unacceptable building deflections or the failure of existing foundations. Obviously, this scenario must be avoided and a design solution will be selected that circumvents this scenario. Solutions include, but are not limited to, ground freezing, ground water lowering, compressed air, shield machines, and cutoff walls. An evaluation of the soil characteristics detailed within Section 4 of this study suggests that ground water inflow can best be controlled by a slurry concrete diaphragm wall for cut-and-cover construction, and that shield or earth pressure balance machine would be most suitable for any proposed mining operations.

The design of the permanent underground facility must, due to the high water table, consider the buoyant force generated by the volume of water displaced by the submerged structure. This force can be overcome by several methods, including: tie-downs, counter balancing dead loads, and permanent dewatering schemes. However, due to the potentially corrosive environment and the relatively long design life of 50 years, it is suggested that a maintenance-free and reliable approach be used. From this perspective, increasing structure dead loads to more than balance the buoyant force, usually by increasing the invert slab thickness, appears to be the most reliable solution.

The method used to construct the Hotel Street Subway essentially pivots on the decision to utilize either the cut-and-cover or the bored tunnel techniques. For Hotel Street, either system could be used. Each has respective advantages and disadvantages as detailed in Sections 5.2 and 5.3, but both techniques will provide a permanent facility that will perform with equivalent levels of satisfaction.

To minimize disruption to surface activities during the construction of the transit system, particularly in the downtown commercial district and the Capital Special District, cut-and-cover construction should be avoided. For this reason, where applicable, the order of magnitude cost estimate in Section 7.8 was based on a suitable bored tunnel construction method, which is generally less disruptive than cut-and-cover construction methods.

Section 5.3.3 describes several appropriate methods of tunneling in the Hotel Street underground environment. They include Slurry Shield, Earth Pressure Balance (EPB) Shield, Extruded Liner EPB Shield, "Figure 8" EPB Shield, Compressed Air Tunneling, and the New Austrian Tunneling Method (NATM). Evaluated as a group, these construction methods can yield a variety of tunnel configurations with individual characteristics that must be analyzed relative to the Hotel Street underground environment. The tunnel configurations examined for the Hotel Street Subway included Twin Circular Tunnels, Twin Circular Tunnels (Stacked Configuration), Single Circular Tunnel (Dual Track), Twin Horseshoe Tunnels, Single Horseshoe Tunnel (Dual Track), and "Figure 8" Tunnels. All of the identified schemes are feasible for Hotel Street; however, based on the available data, twin circular tunnels in a stacked configuration was selected as the most appropriate and used for deriving the order-of-magnitude cost estimate.

The overriding criteria that governed conceptual selection of the tunneling technique involved ground subsidence and ground water control. The operating characteristics of the Earth Pressure Balance (EPB) Shield appears to be most suitable in responding to these critical criteria. The EPB Shield uses excavated ground within a sealed chamber to balance the inflow of ground water. The EPB machine is highly mechanized and can effectively advance a tunnel through a number of geologic conditions including unforeseen obstacles such as wood or concrete piles. It has an advantage over a Slurry Shield which functions in a similar fashion, but requires a large bentonite reclamation plant on the ground surface. As detailed in Section 5.3.3, the other identified tunneling methods have additional disadvantages that detract from their virtues.

Ground displacement is closely related to the geometric configuration of the proposed tunnel and the quality of construction (extent of overexcavation) that can be expected from the proposed construction technique. Each of the tunnel configurations were studied within the context of the Hotel Street environment and a conceptual assessment indicated that the twin circular tunnels would be the most appropriate solution. The circular tunnels are compatible with the EPB Shield technology, they accommodate the alignment constraints and each of the dual tunnels is relatively small in cross section, thereby reducing the potential for large ground displacements.

Portal structures provide guideway transitions between the aerial and underground alignments. Standard tunneling techniques generally require a minimum overburden to preclude a cave-in scenario. At the portal locations the overburden requirements generally cannot be achieved, so construction usually reverts to the cut-and-cover method. This is the expected choice for Hotel Street, and a traditional retained cut construction method is anticipated. The existing soil conditions and congested nature adjacent to the work site, encourage the selection of diaphragm wall construction. Diaphragm walls have the advantage of effectively controlling ground displacements thereby minimizing the potential of inducing structural building damage.

The Hotel Street Subway, as currently envisioned, contains three underground stations identified as Hotel/Bethel, Hotel/Alakea, and Civic Center Stations. Internally, passenger stations are generally configured with platform orientations described as center, side or stacked. Selection of a station configuration is based on an array of parameters including geological constraints, functional/spatial design considerations, expandability, contextual considerations, right-of-way issues, and joint development potential.

The geotechnical boring logs taken along Hotel Street indicate that the underlying coral is not continuous but very irregular with interbedded layers of soft silt and clay found in random, unpredictable locations. These soft materials increase the potential of building damage during excavation of the stations. For this reason the narrower stacked station configuration was chosen, thereby maximizing the clearance between subway construction and adjacent buildings, reducing the risk of settlement damage and providing space to underpin buildings if necessary. These constraints are not an issue for the Civic Center Station, and therefore a traditional center platform station was proposed. The center platform configuration is deemed superior to a stacked platform configuration, especially with regard to passenger circulation.

As with the line or running tunnels, the passenger stations are typically constructed using either mined or cut-and-cover techniques. Two mined-cavern excavation methods have been addressed as a part of this feasibility study. They are the New Austrian Tunneling Method (NATM) and a Jacked Pipe Arch method. Both methods may be feasible but did not appear favorable in light of the existing subsurface conditions. NATM is made very difficult by the relatively high water table and the risks of using compressed air in the voided coral. The jacked pipe arch scheme is complicated by the high water table and the existence of corals that may curtail the ability to jack the pipe sections. Therefore, a traditional cut-and-cover method was identified as the probable solution.

The order of magnitude cost estimate was not performed at a level of refinement to distinguish between a top-down or a bottom-up construction sequence. However, the costs were estimated assuming a concrete slurry wall as the earth retaining structure. A slurry wall has benefits in that it can be used to limit deflections of adjacent buildings much more effectively than other systems. Additionally, a slurry wall can be used as cut-off wall to isolate the station excavation so that dewatering efforts within the excavation will not draw down the surrounding water table, thereby causing additional settlements of adjacent buildings.

Various station arrangements were also analyzed for the three underground passenger stations that fall within the project limits. Three viable schemes were ultimately selected for a detailed comparative evaluation. The three subway options "A," "B," and "C," were evaluated with regard to constructability, environmental impacts, operational efficiency, patronage, and cost. Section 8 contains an evaluation matrix that concludes the alternative scenarios discussed in Section 7 and concisely presents the relevant characteristics of each scheme.

The evaluation matrix that summarizes the three subway options indicates that each alternative possesses relative advantages and disadvantages, corresponding to specific evaluation categories. From an overall perspective, none of the subway options was found to have a distinct advantage. In terms of ridership, Options "A" and "C" were rated superior to "B." Option "B" appeared to be superior in terms of construction impact and transit operations, while Option "A" surpassed the alternatives for the evaluation of long-term impacts.

Option "A" was selected as the solution for the Hotel Street Subway, primarily for the location of station entrances, ridership, and potential for joint development. The probable joint development opportunities identified for Option "A" would also simplify the vertical circulation elements at each entrance location. This is considered highly beneficial as it would eliminate the vertical circulation elements that are presently located within the station platform areas. In conclusion, the recommended scheme is presented in the Reference Drawings that accompanied the *Hotel Street RFP.*

The *Hotel Street Study Report* is a conceptual-level document with a scope of work that is restricted to the Hotel Street Subway project limits. This study does reflect the significant findings to date. However, the current information is limited and no detailed design has been performed. It is expected that further data collection and associated design development will continue to inspire modifications that enhance the objectives of the transit facility.

2. BACKGROUND

Honolulu has considered the implementation of a rapid transit system since the conclusion of the 1967 Oahu Transportation Study. Over the past 20 years, the population of Honolulu has increased by approximately 40 percent, and vehicle registration has grown by 120 percent. On July 25, 1990, after completion of numerous planning and engineering studies, lengthy consideration, and public review of the *Alternative Analysis and Draft Environmental Impact Statement* (AA/DEIS) results, the City and County of Honolulu selected a 17.3-mile fixed guideway rapid transit system with a fully integrated feeder bus network as the preferred transit alternative.

2.1 General System Description

The base system for the Honolulu Rapid Transit Development Project conforms with the general definition of the Locally Preferred Alternative (LPA). The system is located in the City and County of Honolulu. The Mainline originates at the Waiawa Station and extends to the University of Hawaii/Metcalf Station. Waikiki is served by an independent "pinched-loop" that interfaces with the main line at the Kalakaua/Kapiolani Station.

The proposed system will be a fully automatic, electric-powered, grade-separated transit facility that includes 24 passenger stations along 17.3 miles of fixed guideway structure.

2.2 Hotel Street Subway

The Honolulu Rapid Transit Alignment, as defined by the final AA/DEIS document, includes approximately 1.5 miles of underground subway along Hotel Street through the commercial district of Honolulu. For purposes of this study, orientation of the subway alignment will be denoted as Ewa (Waiawa Station direction) and Koko Head (UH/Metcalf Station direction).

The guideway alignment will transition from an aerial structure to an underground facility approximately 1650 feet Ewa of the Nuuanu Stream. It follows the Hotel Street right-of-way, crosses the Capital Special District, and daylights about 300 feet Koko Head of Dreier Street. At the Koko Head subway terminus the guideway transitions back to a grade-separated viaduct structure.

The Hotel Street underground segment encompasses the highest ridership passenger stations and mitigates or eliminates the severe environmental impacts associated with an above-grade crossing through historic Chinatown and Hawaii Capital Special Districts. The major subway components include two portals, three stations, and connecting tunnel sections.

The objective of this study is to ascertain the physical conditions along the subway alignment, evaluate tunneling and station design alternatives, analyze construction methods, environmental impacts, capital cost and service criteria, and in conclusion, recommend a preferred solution for conceptual-level design of the Hotel Street Subway.

The Hotel Street Study has been performed as a series of discrete tasks, all of which were instrumental in developing a feasible design solution. The tasks include:

- Preparation of topographic base maps that illustrate existing right-of-way, building, drainage, and utility information.
- Preparation of prototypical subway station and running tunnel cross sections that reflect functional and structural requirements.
- Conceptualization of reasonable variations of subway configurations that conform to geometric and physical constraints along Hotel Street.
- Evaluation of the proposed alternatives considering design, construction, operation, cost, and environmental factors.
- Review of the proposed alternatives with City representatives and recommendation of the preferred best solution for the Hotel Street Subway.

The Request for Proposals for the Hotel Street Subway Project of the Honolulu Rapid Transit Program has been based on the findings of this study.

3. ALIGNMENT SELECTION

3.1 Introduction

The proposed Hotel Street Tunnel alignment is based on the recommendation documented in the *Alternative Analysis and Draft Environmental Impact Statement*, (AA/DEIS) dated March 1990. The location of existing natural and man-made features such as streams, bridges, and streets, provided constraints which influence the design of the final system alignment. The configuration of the tunnels and location of the associated stations were developed in consideration of these constraints and the system geometric criteria. The alignment is shown on sketches 3.1 through 3.5.

3.2 Alignment Description

The aerial guideway proceeds in the Koko Head direction above Dillingham Boulevard until it passes Ala Kawa Street. Near Station 676+00, the alignment turns in the makai direction and begins a downward vertical curve into a portal at Station 683+80, just makai of Kaaahi Street. The alignment then extends downward, crosses under the Nuuanu Stream at Sta. 700+00, and proceeds under Hotel Street towards Richards Street. The alignment then continues between the State Capital and the Iolani Palace, diverting slightly in the mauka direction to avoid the Mission Memorial Annex Building, goes past the City Municipal Building, turns into Kapiolani Boulevard, and portals Koko Head at Dreier Street within private property at Sta. 764+50, transitioning into an aerial guideway.

Three underground stations are planned for this alignment. The Hotel/Bethel Station is located in the vicinity of Bethel Street, while the Hotel/Alakea Station is located in the vicinity of Bishop and Alakea streets. The third station, Civic Center Station, is located just makai of the Municipal Building, partially within the intersection of South and South King streets. The current location of the Hotel Street Subway stations is the recommended solution of a study that is within the scope of this report and presented in Section 7.

Three major constraints have been identified that affect the selection of an exact alignment and profile for the Hotel Street Subway: the limited right-of-way available along Hotel Street, the existing Nuuanu Stream Bridge, and the geological profile that restricts the tunnel construction methods. The right-of-way restrictions were compounded by historic buildings and high-rise buildings situated along the proposed subway alignment.

The existing right-of-way along Hotel Street between River and Alakea streets is about 50 feet wide. Existing buildings are located at the property line of the Hotel Street right-of-way. As discussed in Section 6, the geotechnical constraints hamper the construction of center-platform stations utilizing parallel tunnels at the Bethel and Hotel/Alakea stations. It appears that a suitable alternative at these locations is to construct vertically stacked side-platform stations that require the line tunnels to be similarly stacked.

The existing Nuuanu Stream Bridge is a three-span, reinforced-concrete structure constructed in 1936. The bridge spans approximately 95 feet between abutments and is supported by two piers located within the stream channel. The abutments and piers are founded on a total of 102 14-inch-diameter timber piles that are driven to a tip elevation of approximately –40 feet. The recommended alignment runs directly under and parallel to the bridge.

Because of right-of-way restrictions, it is impractical to relocate the alignment away from the bridge. It also is impractical to depress the tunnel profile to clear the existing piles and maintain other clearance and grade requirements. In consideration of these physical restrictions, two possible alternatives have been identified:

1. If it is determined that the existing bridge must remain for functional, historical, or cultural reasons, it may be possible to raise the tunnel and protect the bridge through the use of special ground treatment. A possible approach would be to provide a jet-grouted zone under the bridge through which the tunnels would be driven. The jet-grouted zone would minimize settlement of the bridge structure and distribute loads from the bridge piles.

2. It may be determined that this particular bridge has no historical or cultural significance. If so, it would be possible to demolish the existing bridge structure. Then the contractor could drive the tunnel through the existing timber piles at a shallow invert elevation of approximately –40 feet. After the tunnel drive is completed, a new bridge, either pedestrian or vehicular, with foundations straddling the tunnel, could be constructed.

The alignment constraints have resulted in a track profile that must transition from a standard side-by-side parallel track cross section to a stacked track cross section along the relatively narrow Hotel Street right-of-way.

The down station contract limit is located at the beginning of the Ewa portal at Sta. 683+80. At this point, the underground segment is initiated and the track alignment will be parallel and in a uniform horizontal plane. As the alignment approaches the Nuuanu Stream, the tracks will be begin a rotation into a vertically stacked configuration. A profile has been established that would allow either of the alternatives for the Nuuanu Bridge mentioned above to be adopted. The transition to vertically stacked tracks will be completed near Smith Street. The alignment currently positions the Ewa-bound train above the Koko Head-bound train in the stacked configuration.

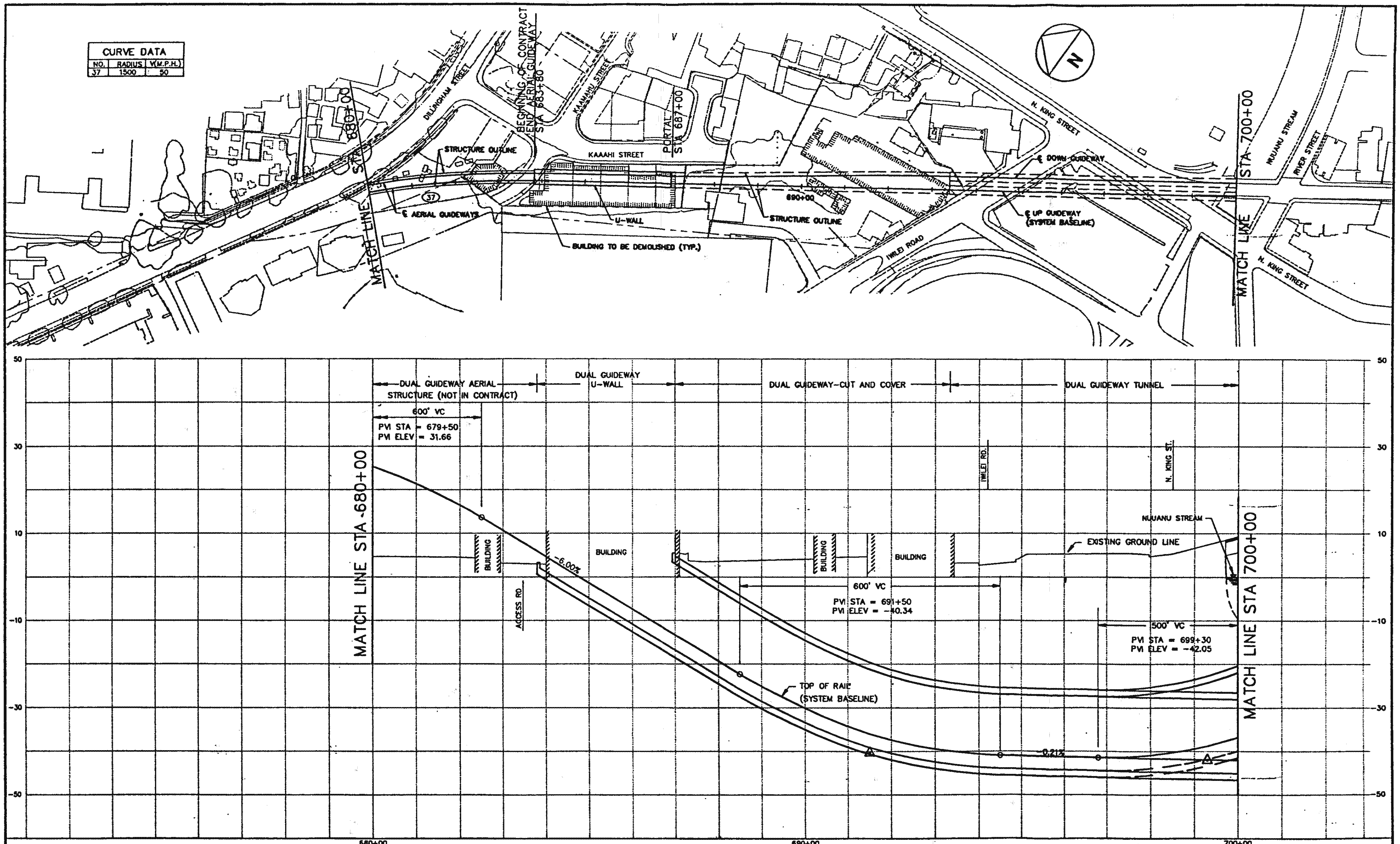
As the tunnels proceed Koko Head of Alakea Station, the alignment will be transitioned back to a parallel side-by-side configuration prior to reaching City Hall. The Civic Center Station will have a typical center-platform configuration. Finally, the track alignment will proceed in the side-by-side configuration to the Koko Head portal for the transition to the aerial guideway at Sta. 764+50. There is no opportunity for a guideway crossover within the Hotel Street underground alignment.

3.3 Conclusion

The selected alignment for the Hotel Street Tunnel was based on the recommendations documented in the *Alternative Analysis* and *Draft Environmental Impact Statement* (AA/DEIS), dated March 1990. The *Hotel Street Subway Study* report did not include further investigation of alternative alignments through the City and County of Honolulu. The selected alignment was evaluated in terms of existing, natural and man-made features located along the proposed route. The limited right-of-way along Hotel Street, the existing Nuuanu Stream bridge, and the geologic profile were identified as three major constraints governing the proposed horizontal and vertical geometry and the associated guideway configuration. Of particular significance is the narrow right-of-way along Hotel Street which is generally straddled by historic two- and three-story masonry buildings or modern high-rise buildings with multi-level underground structures. This condition has resulted in a guideway configuration below Hotel Street that is vertically stacked with Ewa-bound trains running above the Koko Head-bound trains.

The right-of-way constraint also influenced the general configuration of the Hotel/Bethel and Hotel/Alakea stations. Consistent with the guideway configuration, both stations have vertically stacked platforms with the Ewa-bound passenger platform located above the Koko Head-bound passenger platform. Beyond Hotel and Richards streets as the guideway alignment continues in the Koko Head direction, the right-of-way constraint diminishes. Consequently, the guideway arrangement transitions to a traditional side-by-side configuration matching the orientation of a majority of the aerial alignment. The last underground passenger station (Civic Center Station), located near the Municipal Building, is configured as a traditional center platform station with the guideway positioned in a parallel orientation on the same horizontal plane.

Some refinement to the alignment geometry can be expected as the design progresses through preliminary and final stages.



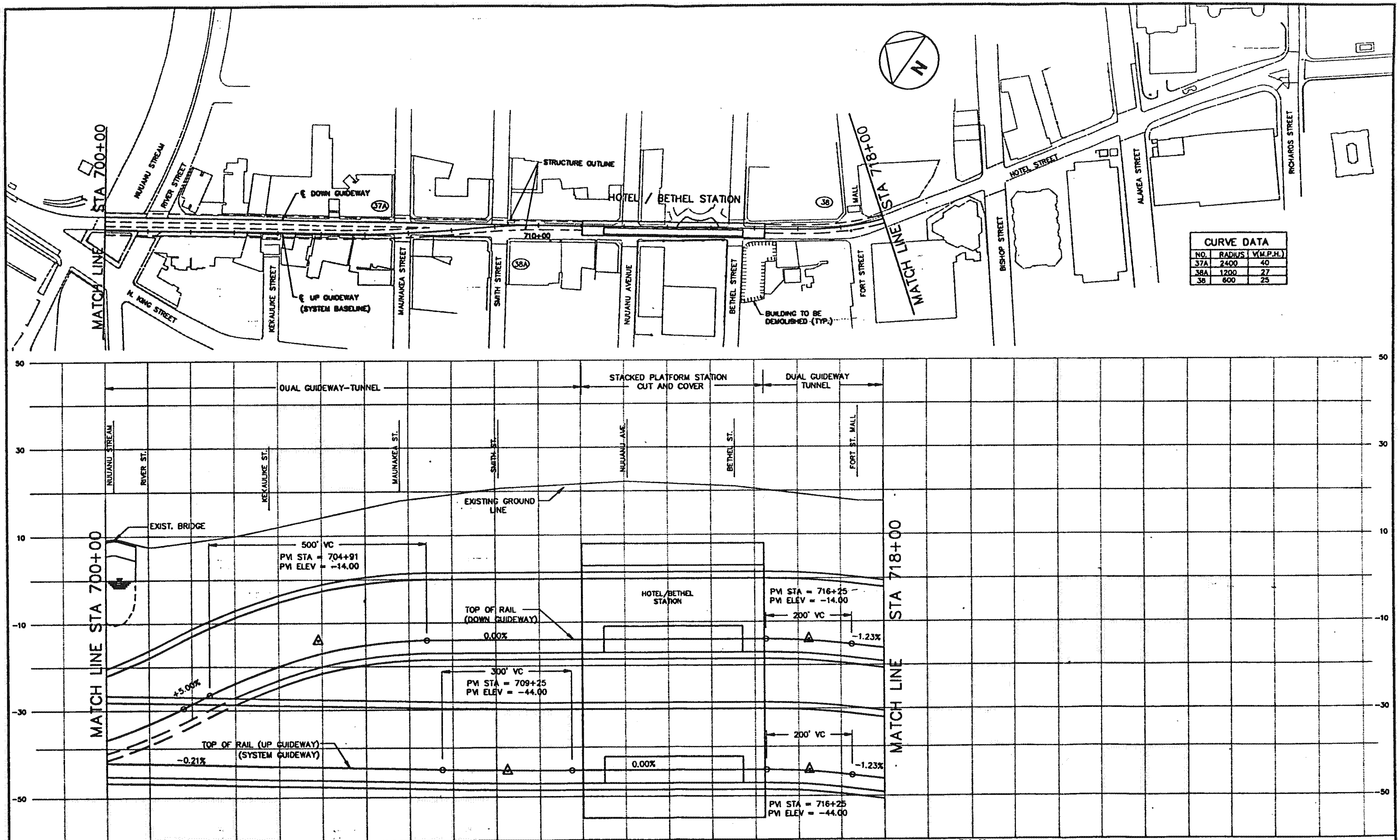
REV	DATE	DESCRIPTION	BY	APP.

HONOLULU RAPID TRANSIT PROGRAM
HOTEL STREET SUBWAY
CITY AND COUNTY OF HONOLULU

PLAN AND PROFILE
STA 680+00 TO STA 700+00

CONTRACT NO.
DRAWING NO. P024
REV. SHEET NO. SK 3.1
SCALE 1"=100' DATE JULY, 1991

HTLALIGN -HRTZ\SYS:\HRT\W\BW\DGN



CURVE DATA

NO.	RADIUS	V(M.P.H.)
37A	2400	40
38A	1200	27
38	600	25

REV	DATE	DESCRIPTION	BY	APP.

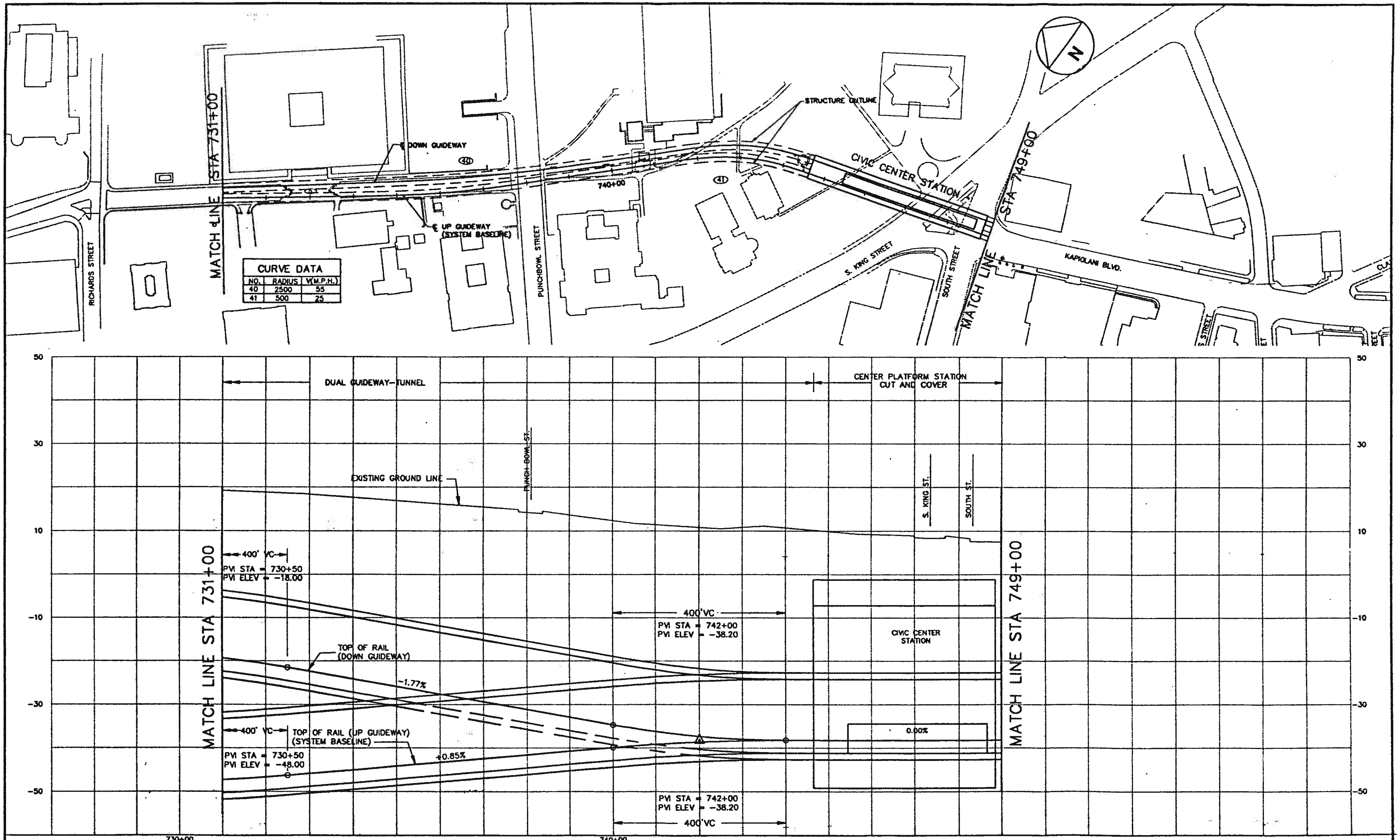
GRAPHIC SCALE
100 / 0 100 200 HORIZONTAL
10 0 10 20 VERTICAL

HONOLULU RAPID TRANSIT PROGRAM
HOTEL STREET SUBWAY
CITY AND COUNTY OF HONOLULU

PLAN AND PROFILE
STA 700+00 TO STA 718+00

CONTRACT NO.
DRAWING NO. P025
REV. SHEET NO. SK 3.2
SCALE 1"=100' DATE JULY, 1991

HTLALIGN –F:HRT2\SYS:\HRT\DB\ALIGN



REV.	DATE	DESCRIPTION	BY	APP.

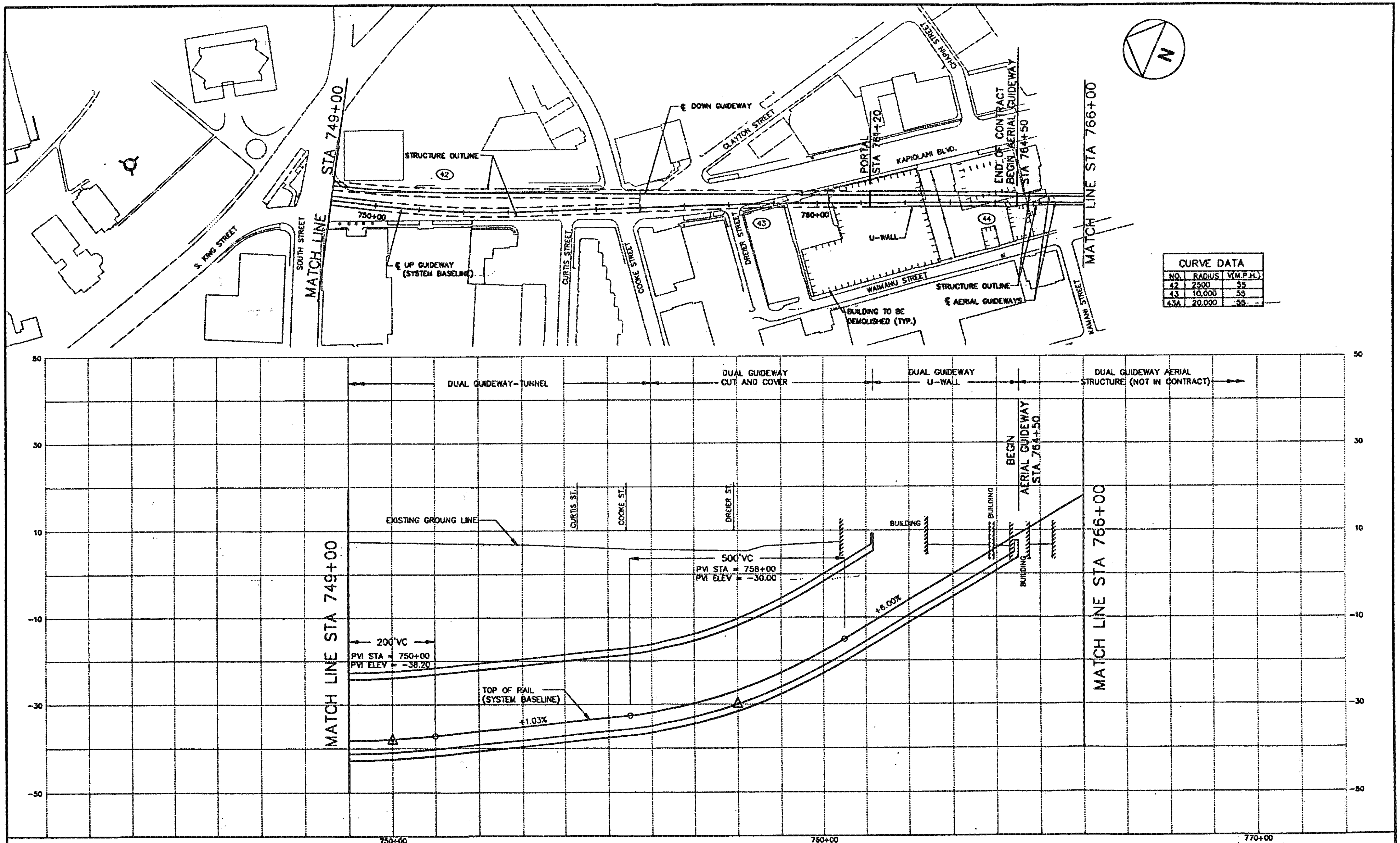
GRAPHIC SCALE
100 0 100 200 HORIZONTAL
10 0 10 20 VERTICAL

HONOLULU RAPID TRANSIT PROGRAM
HOTEL STREET SUBWAY
CITY AND COUNTY OF HONOLULU

PLAN AND PROFILE
STA 731+00 TO STA 749+00

CONTRACT NO.
DRAWING NO. P027
REV. SHEET NO. SK 3.4
SCALE 1"=100' DATE JULY, 1991

HTLALIGN –F:HRTZ\SYS:\HRT\PROFILE\ALIGN



REV.	DATE	DESCRIPTION	BY	APP.

GRAPHIC SCALE
100 0 100 200 HORIZONTAL
10 0 10 20 VERTICAL

HONOLULU RAPID TRANSIT PROGRAM
HOTEL STREET SUBWAY
CITY AND COUNTY OF HONOLULU

PLAN AND PROFILE
STA 749+00 TO STA 766+00

CONTRACT NO.
DRAWING NO. P028
REV. SHEET NO. SK 3.5
SCALE 1"=100' DATE JULY, 1991

HTLALIGN -F:HRTZ\SYS:\HRT\BB\ARGN

4. GEOLOGICAL CONDITIONS

4.1 General Description

4.1.1 The Geology of the Hawaiian Archipelago

The Hawaiian Islands are part of a northwest-southeast archipelago some 1600 miles long, stretching from Midway Island to the "Big Island" of Hawaii. Each island in turn was built up by volcanic lavas emerging from the sea bottom over a stationary "hot spot" in the earth's crust, building up gradually until they emerged at sea level, about 18,000 feet from the ocean depths. These islands often continued to build to heights of many thousands of feet above sea level and, thus, from base to crest, are among the highest mountains in the world. Generally, the lava was a monotonous series of quiet basalt flows of remarkable chemical uniformity that emerged with little violence. A continuing shift in the Pacific Tectonic Plate gradually moved each island to the northwest, allowing new volcanic islands to build up over the "hot spot."

In the southeast end of the Hawaiian Archipelago are the five main islands that make up the State of Hawaii. From oldest to youngest, these islands are Kauai, Oahu, Molokai, Maui, and Hawaii. On the "Big Island" of Hawaii, the island-building process is still going on with almost continuous eruptions of lava to this day, and a submerged sea mount just off the southeast coast of the "Big Island" has almost emerged above sea level.

As each island moved northwest away from the "hot spot" and ceased eruptions, a period of quiescence began that lasted several million years. Coral reefs were formed around the islands in the warm Pacific Ocean waters while sea action broke the basalts that formed the islands into black sands that can still be seen on the newer islands. Eventually, the basalts were chemically weathered to depths of hundreds of feet, and clay minerals were formed by tropical weathering processes. During glacial and interglacial periods, the seas rose and fell worldwide. At the same time, the islands sank into the soft sea bottom and spread laterally due to their own weight, leading to rejuvenated stream cutting accompanied by the formation of swamps and associated lagoon deposits in quiet waters near the shore.

On some of the islands, recent volcanic activity has occurred, often along vents and outlets unrelated to the original formation of the island. These recent eruptions were often violent with spectacular explosions and fire fountains. Lava flows, cinder, tuff, and ash deposits became intermingled with the near-shore coral, beach sands, and lagoonal deposits.

4.1.2 The Geology of Oahu and Honolulu

The island of Oahu was formed by the coalescing of two separate volcanic islands. The Waianae Volcano, in the northwest, moved away from the "hot spot" and ceased eruptions first, and the Koolau Volcano, in the southeast, actively erupted until the Koolau Basalts filled the sea between the two islands. The present Schofield Plateau in the center of Oahu is the remnant of the

Koolau Basalts as they lapped over the older Waianae Volcano basalts that form the mountain range on the west of Oahu.

After the Koolau eruptions ceased, no further volcanic activity occurred on Oahu for about two million years . The island slowly sank of its own weight, some 1200 feet, spreading laterally in the soft sea beds. Coral reefs formed, and wave action created white sand beaches from coral fragments. Various silty lagoons formed near the beaches while the sea level rose and fell during glacial and interglacial periods. The basalt lava flows in the high ground weathered, forming soil to depths of hundreds of feet. Tropical rains eroded the highlands, removing the silt and clay soils derived from the older weathered basalts and carried them down toward the beach.

Abruptly, as little as 50,000 years ago, a new series of volcanic eruptions began: The Honolulu Volcanic Series of about 30 separate events. These eruptions were much more volatile than the monotonous series of the older Koolau lava flows and took place near Pearl Harbor and Honolulu, violently ejecting cinders, ash, and tuff that fell to the ground and were welded into firm beds.

Today, the geology around Honolulu is superficially simple: the volcanic basalt island of Oahu is flanked by coral. However, the interfingering of coral, beach sands, and lagoon deposits with recent Honolulu Volcanic Series ash and tuff and occasional alluvial deposits of silt and clay carried down from the high ground make the microgeology quite complex.

4.1.3 Geology of the Hotel Street Subway

The street level or ground surface along the subway alignment varies from about Elevation +10 to 23 feet above sea level, and in general the water table is found at Elevation 0. Hence, the Hotel Street Subway tunnel will be below the water table.

Hard coral or tuff or unusually loose materials like uncemented beach sands may be simultaneously encountered. However, all of these materials are considered relatively soft. Even the cemented corals have an unconfined compressive strength of only about 5000 to 8000 psi. The only extraordinarily hard, unweathered materials near Honolulu are the young Honolulu Series Basalts, which may reach unconfined compressive strengths of approximately 25,000 psi. However, preliminary exploration indicates these are only locally present at or near tunnel and/or station depth along the Hotel Street Subway. Soft to moderately hard interbedded materials will be the norm.

Along the Hotel Street Subway route, the older, weathered Koolau Basalts are not encountered at the depth of the proposed alignment of the stations and tunnels. However, one lava flow of the newer, fresher Honolulu Series basalts is found near Nuuanu Stream at about 50 to 80 feet below the street level. A different Honolulu Series basalt flow also exists at depth near the Hotel/Alakea Station. In general, the majority of the Hotel Street Subway tunnel will encounter geology consisting of black cinders, coral reef deposits, alluvium, basalt, and tuff. Additionally, near the Nuuanu Stream, some very soft Lagoon Deposits are expected. The following is a brief description of each geological formation:

Black Cinders

Unlike the original uneventful flows that formed the islands, the Honolulu Volcanic Series eruptions were explosive, expelling fragments in the air that settled to the ground as black cinders. These cinders are about the gradation of clean, coarse angular sand. The black cinders are sometimes welded into a firm but not rock-like deposit, with a compressive strength of less than 50 psi. The cinders will stand vertically in some outcrops on Oahu for elevations of 10 to 15 feet.

Black cinders are found along the Hotel Street Subway very near the ground surface, near Station 705+00 and continuously from about Station 713+00 to 764+50; i.e., the end of the Hotel Street Subway route. These deposits are less than ten feet thick throughout except near Station 750+00 where they extend to elevation –35 feet, and are perhaps forty feet thick. The Civic Center Station excavation will encounter this layer of black cinders.

Coral Reef Deposits

During the glacial and interglacial periods, which lasted approximately 2- to 2.5-million years, the worldwide sea levels rose and fell several times. Coral reefs, consisting of shells from very small animals, formed in the shallow water along the changing shoreline around Oahu.

This formation is not continuous, and many openings or voids exist in coral reef deposits. Fine silts and sands that were washed from the near shore into the voids of the reef deposit are typically found. In addition, there are occasional local beds of alluvial materials in the coral reef deposit that also were probably washed from the near shore into the reef. In places the coral is cemented into a firm material that might have a compressive strength of 5,000 psi, but samples obtained and tested along Hotel Street rarely exceed a compressive strength of 200 psi.

Along the Hotel Street Subway, the coral reef deposit is found below the black cinder deposit from about Station 703+00 to the end of the route at about Station 764+50. The coral reef deposit typically extends down to about elevation –30 to –40 feet, except near the proposed Civic Center Station at about Station 750+00. At Station 750+00, the coral is apparently eroded away, resulting in a topographic ravine that was subsequently filled with a thick layer of black cinder. Beyond the black cinder ravine, and within the Hotel Street Subway contract limits, drill holes encountered only coral to depths of 100 feet or more.

Alluvium

Tropical weathering also took place during the 2- to 2.5-million year glacial and interglacial period. This weathering caused the original Koolau Basalt peaks to erode at least 1000 feet to their present-day elevations. Most of the weathering was chemical in nature and produced products such as residual soils, made up of halloysite and montmorillonite clay minerals.

Tropical rains brought these clay and silt-sized minerals down to the shore at the same time that glacial and interglacial periods caused marked changes in sea level.

When studied by conventional civil engineering laboratory gradation test methods, these clay minerals show a measurable shrink-swell capacity even though they have typically agglomerated into silt-size particles. Most of the alluvial silt and clay deposits are now firm clayey silts and sandy gravels, with blow counts ranging from 10 to about 25 blows per foot using a Standard Penetration Test device.

Along the Hotel Street Subway alignment, alluvial deposits underlie the coral reef deposits. The alluvial clayey silts and sandy gravels are found from about elevation –35 to –40 feet, and extend down to the bottom of exploratory drill holes. The alluvial deposits are found from about Station 703+00 to about 740+00, where they are less regular and apparently begin to thin out. By Station 750+00, the alluvial deposits are truncated by the deep topographic ravine now filled with black cinder. No major thickness of alluvial deposits is seen from Station 750+00 to the end of the route.

Tuff

Tuff is a volcanic airborn ash that has settled to the ground and typically become welded from its retained heat into a soft rock. Some tuff has been tested to compressive strengths of about 3000 psi, but because the ash generally settled out in thin layers, drilled cores of tuff are frequently fractured at 1 or 2 inch intervals.

Along the Hotel Street Subway, tuff is seen in adjacent exploratory drill holes from about Station 727+00 for 2000 feet to about Station 747+00. This is probably a continuous bed, geologically similar in origin to the black cinder, but occurring at a much earlier date. The tuff is found at about elevation –40 to –50 feet. One additional bed of tuff was encountered in a drill hole, near Station 750+00, at elevation –75 feet.

Basalt

Koolau Basalt underlies the entire island of Oahu, in some parts being many tens of feet thick. Koolau Basalts are typically old and weathered; however, on a geological time scale the Honolulu Basalts are relatively young and unweathered. The Honolulu Series Basalts are very hard and have a tested compressive strength of approximately 25,000 psi.

Along the Hotel Street alignment, the Honolulu Series Basalt is initially encountered near Station 699+00 at elevation –85 feet. The Basalt elevation rises to approximately –60 feet at Station 703+00, and levels off to about –50 feet for the remainder of the subway route, and is estimated to be approximately 20 feet thick. Near the lower levels of the proposed Hotel/Alakea Station, a stratum of basalt is found sandwiched between coral reef deposits. Basalt may be encountered during construction of the lower portion of the Hotel/Alakea Station and possibly in the invert area of the lower mined tunnel near Station 730+00.

Lagoon Deposits

In the low-energy environment that characterizes the island of Oahu's shores, beaches are formed from coral reef deposits and lagoons continue to be formed in areas surrounding quiet waters. The halloysite and montmorillonite clay minerals derived from the weathered Koolau Basalts are washed down from the highlands and can accumulate to substantial thicknesses. These silt and clay deposits typically have a dry density of less than water (40-60 lb/ft^3) and a very high moisture content (70 to 90 percent), with very low undrained shear strength (300 to 500 lb/ft^2). The blow count using a Standard Penetration Test ranges from about 0 to 5. The lagoon deposits also include some cobbles and boulders that were apparently brought down from the highlands during brief periods of high-energy stream flow.

There are substantial lagoon deposits at the Ewa end of the Hotel Street Subway route. The deposit extends approximately 1600 feet from Station 687+00 to Station 703+00. The lagoon deposits overlay the Koolau Basalt, and are between 40 and 85 feet thick. The deepest area of lagoon deposits is located near the Nuuanu Stream.

4.2 Tunneling Constraints

The Honolulu Rapid Transit System will be an aerial structure from its Ewa end near the Leeward Community College up to about Station 683+80 where the system descends to ground level near Dillingham Boulevard and North King Street. At this point, the alignment will transition below grade through the Ewa portal structure.

The line will continue underground following Hotel Street to Richards Street, past the Iolani Palace and the Municipal Building to a Koko Head portal structure near Dreier Street and Kapiolani Boulevard. The portal structure terminates at Station 764+50, and the guideway continues in the Koko Head direction as an aerial structure. The length of the Hotel Street Subway is approximately 8000 feet measured from portal to portal.

The underground tunneling constraints are considered with respect to the following principal structures, each of which have unique characteristics when considered relative to the local geology:

- Ewa portal
- Hotel/Bethel Station
- Hotel/Alakea Station
- Civic Center Station
- Koko Head portal
- Running tunnels.

Ewa Portal

The portal and associated U-wall structure will be located in very soft lagoon deposits. Dewatering the lagoon materials will be difficult to impractical. Conventional sheet piles may be used to construct the cut-and-cover structure; however, seating the sheet piles in the underlying basalt may be difficult. Slurry-wall construction may not be feasible because the lagoon material must remain stable during the excavation process, which relies on bentonite slurry for support.

The water table is very near the ground surface. Consequently, the permanent structure must be designed for significant uplift forces. Concurrently, the design must comply with stability requirements and permissible soil stress levels.

Hotel/Bethel Street Station

From River Street at the Nuuanu Stream going Koko Head on Hotel Street to Bethel Street, the route transverses the historic Chinatown Special District. The buildings are generally 2- and 3-story brick and concrete-block structures; the street is narrow and, in some cases, the actual building-to-building distance is only about 50 feet. In Chinatown, the available right-of-way is so narrow that the currently proposed tunnel transitions from a standard horizontal geometric configuration to vertically stacked orientation to allow for the Hotel/Bethel Street Station construction.

At the Hotel/Bethel Station, borings indicate that no basalt or soft lagoon deposits will be found. Firm and cemented corals exist as well as some uncemented beach sands that could ravel and/or run if not controlled during excavation. Alluvial deposits, including some stiff clays, are found at an approximate elevation of -45.0.

In the narrow right of way available in Chinatown, the possibility of settlement caused by station construction is cause for concern. Excavation for this station could be supported by slurry-wall construction methods. This method would enable groundwater to be pumped out inside the slurry wall to be pumped out without drastically lowering groundwater outside the wall. This technique, which uses relatively stiff walls, generally prevents large ground deformations; however, some settlement is still likely to occur.

Hotel/Alakea Street Station

Similar to the Hotel/Bethel Station, the Hotel/Alakea Station borings indicate that coralline gravels, silty gravels, sandy silts, and silty sands will be encountered. The materials are partially cemented, creating a firm but easily excavated material. Again, a slurry wall may be used to construct this station so that dewatering of the station during construction will not significantly lower the adjacent water table under nearby buildings.

Although the ground materials are firm and dewatering can be controlled by the slurry-wall method, ground settlement due to deep station construction for the stacked tunnels may still be a problem. The mat foundations of some nearby major buildings are sensitive to settlements. Therefore, monitoring of settlements during construction and a building protection program will be required.

Civic Center Station

Borings revealed that a hard coral ledge exists at the Civic Center Station, from about 10 feet to 45 feet below ground surface. Below this are alluvial sand and silts. At about the Koko Head third of the subway station, a deep deposit of black cinder exists. This station is not located under the very narrow Hotel Street right-of-way and, by comparison, is relatively far from structures requiring mitigating measures to control ground settlements. Numerous construction options are available, but the selected method must address the potentially high groundwater inflow through the pervious corals and alluvial deposits. The options include, but are not limited to, mined cavern or cut-and-cover construction using ground stabilization methods such as slurry walls, secant piles, or ground freezing techniques. The variations are unlimited and the most advantageous solution will be influenced by the selected contractor's construction expertise, availability of equipment, and the design results associated with preliminary engineering.

Koko Head Portal

Borings indicate that coral deposits will be encountered during excavation and construction of the Koko Head U-wall portal structure. There are no exceptional conditions that would inhibit the use of traditional excavation support followed by conventional bottom-up construction.

Running Tunnels

Mined subway tunnels for in-bound and for out-bound trains will probably be built from the portal at each end of the Hotel Street Subway. The tunnels will be below the water table for their entire route, and the design must inhibit ground water inflow.

The current alignment requires that the guideway tunnels transition from a standard parallel guideway cross section to a stacked configuration upon entering the narrow right-of-way along Hotel Street. The proposed horizontal and vertical alignment of the dual tunnels may induce complex settlement patterns that should be monitored. This matter is of particular concern at the Ewa end of the alignment where tunneling will encounter the very soft lagoon deposits.

As the alignment extends Koko Head, soil conditions will vary from lagoon deposits to alluvial and coralline deposits. Some basalt and tuff is expected to be encountered locally. The detailed design and construction methods must achieve tunnel line and grade and preserve adjacent buildings from settlement damage.

The following discussion of the Hotel Street Subway tunnel geology goes "up station" but does not imply that one or both the tunnels will necessarily be constructed in the "up station" direction.

Ewa Portal to Station 693+80

The transition from portal structure to mined tunnels would be constructed in lagoon material. Lagoon material is so soft that special measures must be taken upon entering and/or exiting the portal structure so that the tunnel does not "dive" or deviate off course. Construction of the second tunnel may induce additional loads or deformations on the initial tunnel, which may be amplified by the local soil conditions. Soil stabilization using jet grouts or chemical grouts may be used as a special measure to mitigate these difficulties.

Station 693+80 to 702+00

At the Nuuanu Stream, the design and the tunnel construction technique must address stream flow and the presence of wooden piles that support the existing Nuuanu Stream Bridge. It is expected that the existing bridge will be under pinned to retain current-day capacities or be demolished and replaced to meet preestablished design requirements.

Tunnel construction may be impeded by random boulders distributed in the lagoon deposit as well as the basalt along its invert.

Station 702+00 to Hotel/Bethel Station

The upper tunnel will exit lagoon material and enter coral and sandy materials derived from coral at about Station 703+00. The distinction between the cemented corals, poorly cemented corals, and loose sand derived from coral depends upon the cementation of the sand-size particles and cannot be predicted. The variation in the ground will not be considered mixed face although cemented coral may reach 5000 to 8000 psi unconfined compressive strength. The lower tunnel will encounter firm alluvial silt and clay, with no basalt in the invert, at about Station 703+00.

Hotel/Bethel to Hotel/Alakea Station

Between the Bethel and Alakea stations, an upper tunnel will be in coralline gravels and sands, and a lower tunnel will be in alluvial silts and clays. No mixed-face conditions are anticipated although basalt is found at depth on the Koko Head side of the Hotel/Alakea Station.

Hotel/Alakea Station to Civic Center Station

The upper tunnel will encounter coralline gravels with increasing cementation, and near the Civic Center Station, both tunnels will encounter a hard, well-cemented coral. Initially, the lower tunnel will be in firm alluvial silts and clays but will encounter basalt in the invert from about Station 729+00 to 732+00, which is considered a mixed-face condition. Between the Hotel/Alakea and Civic Center stations, the tunnel alignment transitions from a stacked to a parallel configuration.

Civic Center Station to Koko Head Portal

From the Civic Center Station to the portal structure on the Koko Head end of the Hotel Street Subway, black cinder (coarse clean sand), coralline materials (cemented and uncemented), and a few alluvial silts and clays will be found.

In hard-rock underground work, the groundwater level has relatively little influence on the design and construction. Even in cases of spectacular water inflow, men can be transported to the heading and successfully work. However, in the Hotel Street Subway, the ground is not continuously hard, and much of the material could collapse below the groundwater table. Soft ground conditions dominate the route. The groundwater level is up to 60 feet above the work. The groundwater must be controlled during excavation of tunnels and subway stations to prevent seepage, piping, and collapse of the soft ground. Pumping groundwater can influence the settlement of adjacent buildings in certain compressible ground types.

Construction of subway stations is assumed to be by open-cut excavation using concrete slurry walls for excavation support. The slurry walls are designed to isolate the groundwater and permit groundwater pumping within the station excavation without significantly lowering the groundwater beyond the perimeter of the proposed stations.

If the geologic conditions on the Hotel Street Subway were rock, quite different construction equipment and techniques would be recommended. Settlement of structures above the tunnel would be a relatively minor concern. Along much of the Hotel Street Subway route in downtown Honolulu, coral reef deposits are found a short distance below street level. It is possible that cementation in the coral reef deposits may locally transform the reef materials into a rock-like mass and, in that case, settlement and building damage could be very small. However, in reaches where the coral reef material is poorly cemented, the ground will behave like loose sands and silts below the water table.

Tunneling in loose sands and silts below the water table inevitably results in a certain amount of extra ground being removed from the excavation, and this "lost ground" appears as a settlement trough on the ground surface above the tunnel. In isolated country areas, this subsidence of the ground surface might be unnoticed or generally acceptable. In the Hotel Street, however, the proposed subway is adjacent to buildings that could be damaged by the inevitable settlement.

Standard techniques for calculating the width of the settlement trough depend upon the amount of "lost ground." Very good tunneling techniques might result in only about 2 percent of the excavated soil becoming "lost ground," (i.e., 102 percent of the theoretical volume was in fact excavated). Poor tunneling techniques or unexpected loose running ground or tunneling methods completely unsuited to the actual ground conditions might result in about 5 percent "lost ground."

Measurements on many projects show that the actual amount of ground movement and rearrangement is greatest near the tunnel crown. This rearrangement at depth rapidly migrates upward to street level at an angle that varies with the ground type, and creates the settlement trough.

Some types of buildings, such as those founded on end-bearing piles in a stratum not affected by tunneling, will not be damaged by the settlement trough and the resulting differential settlement. Buildings on friction piles or mat foundations may be distorted by the settlement trough and suffer varying degrees of stress. Important utilities may be affected. Historic buildings and monuments, especially those made of brick, are sensitive to differential settlement; many such buildings and statues are found within the project limits.

Careful surveys can show where the tunnel is at any given time so that building distress can be monitored around the clock. Preventative actions can limit building damage and, if necessary, remedial measures such as controlled grouting can be employed at the same time that the tunneling work is passing significant structures.

4.3 Conclusion

The geology encountered along the Hotel Street Subway alignment is mixed and highly complex when appraised from the perspective of underground construction. The major geological constituents include black cinders, coral reef deposits, alluvium, basalt, tuff and lagoon deposits. This environment is further complicated by the local ground water elevation, which is measured to be approximately 10 to 20 feet below the ground surface. These conditions will be a major consideration influencing the methods proposed for subway construction, and the final design characteristics of the permanent structure.

With the exception of basalt, all of the materials are considered to be relatively soft. The Honolulu series basalts, however, are extraordinarily hard and may reach unconfined compressive strengths of approximately 25,000 psi. Tunneling and excavation equipment is most efficiently designed and effectively utilized when it is operated in a homogenous environment. An analysis of the geologic profile revealed that the extremely hard basalts were found at minimum depths of -50 to -60 feet. In a conscientious effort to avoid a mixed (hard versus soft) tunneling environment, the vertical alignment was established to avoid the regions consisting of basalt. By adhering to this objective it was rationalized that construction difficulties would be reduced with a corresponding savings in cost. However, the actual below grade conditions can never be predicted with exact precision, but only with a degree of certainty that is measured by the extent of the geotechnical investigative program. This publication is based on very limited geotechnical data.

It is currently assumed that all of the construction will occur in relatively soft materials. The lagoon deposits found near the Nuuanu Stream are so soft that some form of ground improvement technique will probably be required, regardless of the selected construction method. Ground improvement techniques typically consist of jet grout or chemical grout; both serve to strengthen soil.

Ground displacement, settlement, and deflections are all of concern, particularly in soft soils along the highly developed Hotel Street alignment. It is imperative that the design and construction carefully consider and monitor potential ground displacements so as to mitigate the possibility of inflicting structural damage on adjacent sensitive buildings. As stated earlier, the geology is complex consisting of a non-homogenous mix of materials. The corals are interwoven with alluvial clays, silts and sandy gravels. The disjointed nature of this material will make the magnitude and profiles of any settlement troughs very difficult to predict.

The mitigation measures entail extensive geotechnical analysis, utilization of construction techniques that characteristically minimize ground displacement, and the implementation of a comprehensive monitoring program. These measures are applicable to mined and cut-and-cover construction methods, although each have particular advantages and disadvantages that are described in detail under Sections 5 and 6.

The ground water elevation is an additional concern during the construction period and service life of the transit facility. With the exception of isolated segments of surface penetrating structures, the entire subway is located below the water table. This has a particularly severe impact when construction is considered in light of the existing soil conditions. A high percentage of the soil is quite pervious, thus high volumes of ground water inflow can be expected along excavated or open surfaces which extend below the water table. Additionally, if water is permitted to flow freely into an excavation or mined tunnel, it is likely to carry fines or small particles of soil that constitute the natural state of the ground. Should a significant amount of fines be lost by ground water inflow, the supporting capacity of the immediate ground will be lost. The consequence could be unacceptable building deflections or the failure of existing foundations. Obviously, this scenario must be avoided and a design solution will be selected that circumvents this scenario. Solutions include, but are not limited to, ground freezing, ground water lowering, compressed air, shield machines, and cutoff walls. An evaluation of the soil characteristics detailed within Section 4 of this study suggests that ground water inflow can best be controlled by a slurry concrete diaphragm wall for cut-and-cover construction, and that shield or earth pressure balance machine would be most suitable for any proposed mining operations.

The design of the permanent underground facility must, due to the high water table, consider the buoyant force generated by the volume of water displaced by the submerged structure. This force can be overcome by several methods, including: tie-downs, counter balancing dead loads, and permanent dewatering schemes. However, due to the potentially corrosive environment and the relatively long design life of 50 years, it is suggested that a maintenance-free and reliable approach be used. From this perspective, increasing structure dead loads to more than balance the buoyant force, usually by increasing the invert slab thickness, appears to be the most reliable solution. Also, waterproofing details that are usually fully developed during the final design phase, must carefully consider the underground environment and meet the leakage rate design specifications.

5. LINE TUNNELS

5.1 Introduction

In traditional subway construction, two types of running or line tunnels are typically considered; cut-and-cover tunnels and bored tunnels. The two types of tunnels are differentiated by the construction method involved. Both methods have various advantages and disadvantages depending upon the particular conditions encountered. This section will provide an overview of each method and discuss their applicability to the Hotel Street Subway.

5.2 Cut-and-Cover Tunnels

5.2.1 Introduction

Cut-and-cover tunneling is the traditional method of underground construction and as such is utilized daily, albeit on a small scale, for the construction of underground utilities. It is a relatively straightforward method, familiar to many general contractors, utilizing readily available technology.

In cut-and-cover tunneling, a temporary earth retaining system is first installed from the ground surface. The retaining system might consist of steel sheet piles, soldier piles and lagging, or a concrete slurry wall. The choice of system would be dependent upon the depth of excavation, geotechnical conditions, structure configuration, and proximity of surrounding structures.

The earth between the retaining walls is progressively removed and struts placed between the walls to support the excavation. Once the desired elevation is reached, the structure is constructed within the excavation, the excavation backfilled, and the temporary retaining system removed or abandoned in place.

Construction is complicated by the presence of a high water table and permeable soils. Such a condition requires the installation and operation of dewatering equipment to allow the construction to progress without the potential of water infiltration and/or ground destabilization. If the soil consists of soft clays or silts, the lateral loads on the retaining walls will be sizeable, especially for a deep excavation as required for subway construction. The presence of adjacent structures must be carefully considered before beginning construction, and the temporary retaining system must be designed and constructed to minimize damage to these structures.

5.2.2 Configurations

One of the greatest advantages of cut-and-cover tunneling over bored tunneling is it's adaptability. The designer has the ability to vary the tunnel configuration along the line as necessary to meet specific operational requirements. The tunnel can be constructed as a single cell or with multiple cells, narrow or wide, horizontally or vertically oriented as required.

In contrast, by nature of the construction process, a bored tunnel's configuration cannot be varied along the alignment. The configuration is established by the characteristics of the selected tunnel boring machine. The boring machine is generally used throughout the length of the drive, and as a result, the tunnel cross section is a constant. Therefore, at several locations along any subway alignment, such as at special trackwork areas (turnouts, crossovers, switches, and pocket tracks), it will be necessary to use the cut-and-cover tunneling method or a hand-mined tunneling method. Hand mining refers to relatively labor intensive tunnel excavation that utilizes a combination of manual labor and power-operated excavation equipment.

Typical configurations for cut-and-cover subway tunnels are illustrated in Sketches 5.1 and 5.2. Sketch 5.1 depicts a standard parallel track configuration. The primary advantages of this cross section are reduced excavation support, enhanced flexibility for crossovers, special trackwork, and cross passages.

A stacked guideway configuration is illustrated in Sketch 5.2. The major advantage of the stacked concept is the reduced structural width and consequent reduction in required right-of-way. This configuration limits the feasibility for crossovers, special trackwork, and cross passages.

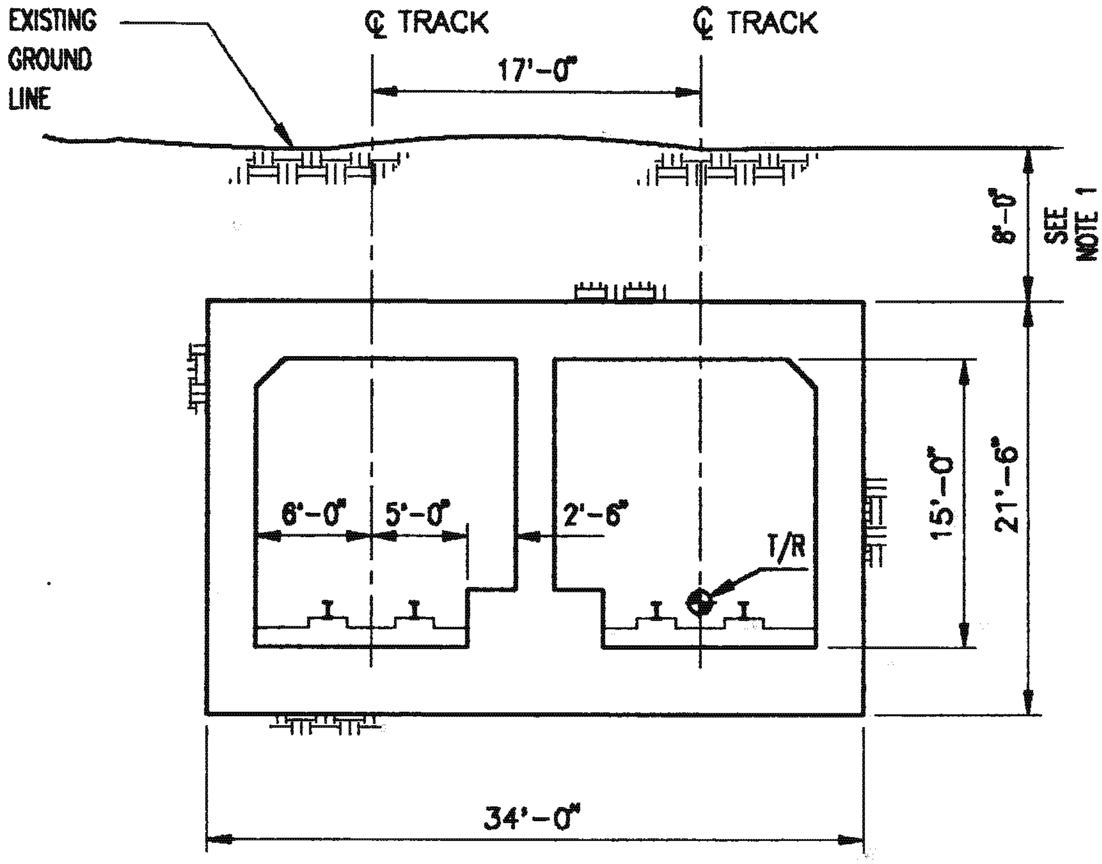
Cut-and-cover structures can readily transition between different configurations. Typical line tunnels could include single, double, or multiple cell-box structures. They are also appropriately used in areas of the alignment where dual guideway centerlines are in such close proximity that twin bore tunnels become geotechnically impractical or geometrically impossible.

For an alignment with limited right-of-way, such as along Hotel Street between River and Richards streets, it might be desirable to orient the tracks vertically in a double-cell, vertically stacked box as shown in Sketch 5.2. The vertically stacked cut-and-cover tunnel would allow the tracks to be placed closer together than possible with a similarly arranged bored-tunnel alternative, thereby potentially reducing relative depths of the Hotel/Bethel and Hotel/Alakea stations. The resultant station depths would be governed by functional clearances within the station. The double-cell, vertically stacked box could be transitioned into a double-cell, side-by-side box between Alakea and Civic Center stations.

5.2.3 Construction Method

Irrespective of the configuration desired, the construction of any cut-and-cover tunnel follows the general procedures outlined above; i.e., installation of the earth retaining system, excavation and bracing, construction of the structure, and finally backfilling of the excavation. There are two major variations of the general construction method utilized for cut-and-cover construction. These are typically referred to as "bottom-up" and "top-down" construction. The top-down method is discussed in detail in Section 6.5 under Construction Methods.

Bottom-up construction is the traditional and most commonly utilized method of cut-and-cover construction. This method requires the installation of struts between the temporary retaining walls in a progressive manner as the excavation proceeds downward. The result is that as the excavation progresses, the contractor has a large open hole within which to work. This large

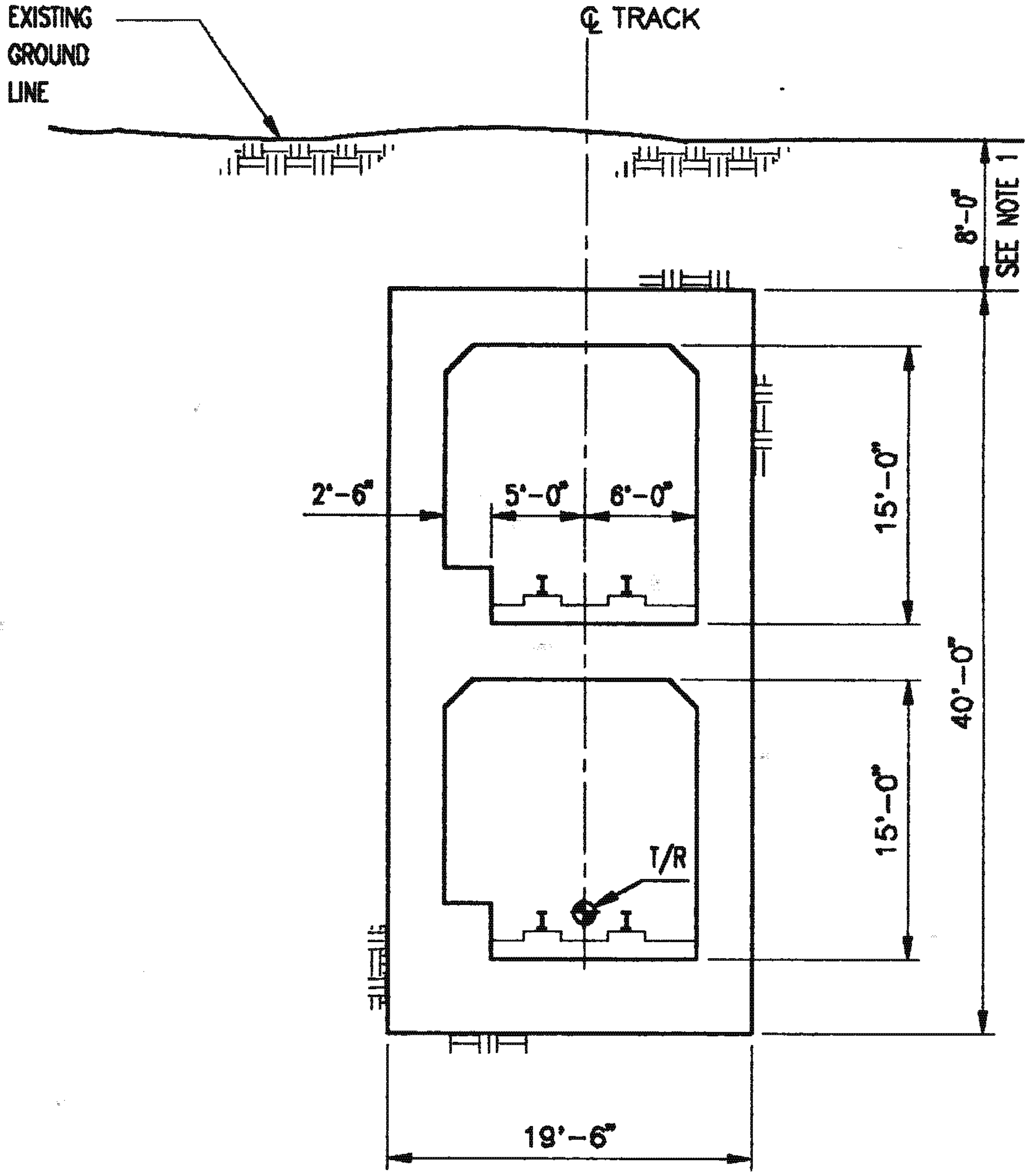


SKETCH 5.1 - CUT AND COVER TUNNEL

NTS

NOTES: 1. DIMENSION VARIES. THE INDICATED DIMENSION IS A MINIMUM VALUE, PROVIDING RESERVE SPACE FOR EXISTING AND FUTURE UTILITIES.

2. T/R = TOP OF RAIL



SKETCH 5.2 – CUT AND COVER TUNNEL (STACKED CONFIGURATION)

NTS

NOTES: 1. DIMENSION VARIES. THE INDICATED DIMENSION IS A MINIMUM VALUE, PROVIDING RESERVE SPACE FOR EXISTING AND FUTURE UTILITIES.

2. T/R = TOP OF RAIL

open hole makes it easy for the contractor to complete the excavation, provides excellent construction access, and gives him plenty of room to construct the tunnels.

As the Hotel Street Subway alignment runs through permeable soils, completely below the water table, it will be necessary to dewater the site ahead of the excavation. Once the lowest excavation elevation is reached, the tunnel base slab is constructed, stabilizing the bottom of the retaining walls. Then, inner walls and the roof slab are constructed. Waterproofing, if required, is placed prior to construction of the respective box-section elements. In progressive order working upward, the excavation is backfilled and intermediate struts are removed. Once the backfilling is completed, the street surface is restored and opened to traffic.

It is anticipated that any cut-and-cover tunneling along the Hotel Street alignment would be accomplished using concrete slurry walls as the earth retaining structure. A slurry wall has benefits in that it can be used to limit deflections of adjacent buildings much more effectively than other systems. The second advantage of the slurry wall is that it can be used to isolate the excavation (a cut-off wall) so that dewatering efforts within the excavation will not draw down the surrounding water table, thereby causing additional settlement of adjacent buildings. Finally, a properly constructed slurry wall can act as the permanent structural wall, eliminating the need to construct an inner wall within the excavation. This method is known as "single-wall construction" and is addressed further in Section 6.5, under Construction Methods.

A tremendous volume of spoil materials will have to be removed from the site during excavation. An equally large amount of concrete, reinforcing steel, and other construction materials will have to enter the site during station construction. The large open hole provided by the bottom-up construction method provides almost unlimited access to the site and easily facilitates these activities. Construction vehicle access can be provided by the installation of a temporary deck over a portion of the excavation to allow partial restoration of vehicular traffic on the street above. This would also allow the maintenance of emergency vehicle access to Hotel Street.

5.2.4 Concerns

Disadvantages of cut-and-cover construction include maintaining safety around the excavation, conflicts with buried utilities, difficulty in limiting the settlement of surrounding structures, and long-term disruption of surface activities including impacts on adjacent businesses. Maintaining safety is a relatively simple matter but must be addressed by the contractor in a diligent manner through adequate usage of fencing, barriers, traffic decking, and signage.

A major concern in any open excavation planned for a public street is conflict with underground utilities. Cut-and-cover tunnels are typically located a considerable distance below the street level for operational requirements. Therefore, it is normally possible to temporarily support the underground utilities as the tunnel excavation proceeds in lieu of physically relocating them. The utilities under Hotel Street have been reviewed and although there is a tremendous number to contend with, no serious conflicts with possible tunneling were identified.

From an engineering standpoint, the greatest problem that occurs with cut-and-cover construction has to do with the surrounding surface settlements generated by the excavation. As the excavation in traditional bottom-up construction progresses, steel struts are installed and prestressed to support the retaining wall. Unfortunately, regardless of the magnitude of the prestressing, the struts shorten and the walls deflect inward as the excavation progresses.

The extent of the problem can be reduced by using thick slurry walls, close strut spacing and high levels of strut preload. However, the inward wall deflection and subsequent surface settlements will often still be unacceptable. This is particularly true where old masonry buildings are found adjacent to deep excavations, which is exactly the situation presented along the Hotel Street alignment.

Settlement of surrounding structures can be minimized by proper design and careful construction of the earth retaining system and bracing combined with a diligent ground movement monitoring program and building protection plan. However, even with the most careful planning and construction, some settlement of existing structures can be expected. The goal should be to try to limit such settlement to an absolute minimum.

Long-term disruption of surface activities covers several aspects of life in the area surrounding a cut-and-cover construction site. Initially, traffic at the construction site will need to be detoured while the initial excavation is accomplished. This detour would cause only minor disruption along Hotel Street, particularly at intersections of cross streets. To reduce the impact, public transit will be rerouted to other parallel city streets. Decking would be required at the intersection for a duration of approximately 2½ years.

A further disruption to the local quality of life is caused by the construction activities themselves. This disruption includes noise and dust generated by the construction haul vehicles and heavy equipment working at the site, problems with restricted access to businesses, and temporary utility outages. These potential problems are usually addressed in the technical specifications that accompany construction contract documents. For example, construction traffic movements might be limited to daylight working hours to avoid disturbing local residents at night. Similarly, disturbance of local businesses can be held to a minimum by careful planning and rigid technical specifications.

5.3 Mined Tunnels

5.3.1 Introduction

The history of mined tunnels is interesting, and records indicate that the first mined tunnels may have been built in pre-Biblical times. Today, mined tunnels are utilized extensively throughout the world for many applications, including transportation facilities.

Mined tunnels, literally had their origins as hand excavations in earth. The construction and relative success of tunneling operations was very much a function of surrounding geology and soil conditions. Even today, the general feasibility and overall design of a mined tunnel is substantially a direct correlation with the geologic parameters.

Numerous mining methods have been devised over the years to cope with a multitude of tunneling environments. Mined tunnels have been constructed in materials ranging from extremely hard rock to very soft clays and silt, all with varying exposures of hydrostatic head, and each with unique geological profiles requiring unique design solutions. The analysis and design process generally entails evaluation of ground deformation, surface settlement, water infiltration, and support mechanisms for initial and primary tunneling conditions. Tunnel construction requires constant monitoring of the surroundings to verify that the soil response is within the forecasted design limits. Any perceptible deviation requires immediate analysis followed by corresponding modification to construction technique to ensure the stability of the tunnel and/or protect the existing buildings.

Mined tunnels are attractive because they are unobtrusive to surface activities during construction and service operation. They generally function unnoticed for decades and require a minimal amount of maintenance effort. In addition, the capital cost of a mined tunnel may be a significant advantage over other tunneling techniques, particularly when excavations are deep or surface disruption becomes prohibitive.

5.3.2 Tunneling Environment

As previously discussed, the tunneling environment is instrumental in determining construction technique and final tunnel structure design. This section provides a brief overview of tunneling environments likely to be encountered along Hotel Street, and applicable construction methods.

Rock

The traditional methods of tunneling through rock involves either a "drill-and-blast" method or a tunnel boring machine (TBM). Drill-and-blast equipment has a much lower initial start up cost; however, it is labor intensive and production rates can be sporadic. Alternatively, a modern TBM has a very high initial cost and usually requires a long length of rock tunnel to substantiate economic viability.

Tunneling in rock is not anticipated along the Hotel Street Subway alignment. Some volcanic ash (tuff) with a compressive strength of about 3000 psi; and cemented coral with a compressive strength of about 5000 to 8000 psi, might be considered "soft rock," but these are discontinuous and a TBM could be selected that can cut through these soft rocks without difficulty. A few local outcrops of hard basalt might be encountered at depth, near Nuuanu Stream and Koko Head of the Alakea Station. These are not typical, and would not govern the selection of a TBM. Hard basalt, if encountered in isolated locations, could be excavated by predetermined methods such as hand mining through the face of a boring machine.

Mixed-Face

Mixed-face tunneling implies that there are two or more types of ground encountered simultaneously in the tunnel face, which have such different properties and behavior that they are difficult to mine through without changing the routine of the methods and/or equipment used. A tunnel crew set up and well used to soft ground equipment and methods might encounter a mass of hard rock; or a rock tunnel crew with drill-and-blast equipment could encounter soft ground. In mixed-face tunneling the unexpected change of materials and contrast in the properties of the materials may make the initial equipment and personnel unusable, especially if the change is not anticipated.

For the purposes of this report, mixed-face will refer to geologic zones of extraordinary contrast, such as tunneling from a soft lagoon material into a partially basalt face, from lagoon material into coral, or from lagoon material into alluvial deposits, or vice versa. The Hotel Street Tunnel is likely to traverse all of these materials, in addition to man-made obstructions such as tiebacks. Although it is feasible to obtain modern TBMs that have the capability to cope with mixed-face conditions, careful scrutiny and evaluation will be required prior to choosing an appropriate mining method for Hotel Street.

Soft Ground

Soft-ground tunneling applies to any material that will not support itself for a significant length of time and that therefore must be supported as fast as it is tunneled. In general, soft-ground tunneling may advance by hand or TBM mining methods. A tunnel shield is commonly used in soft-ground conditions. It consists of a steel cylinder with overall dimensions equal to the tunnel bore and houses the men and mechanical equipment used to excavate the tunnel.

Only a relatively short length of the Hotel Street Subway qualifies as soft ground, and this material is located in the vicinity of the Nuuanu Stream. The selection of the mining technique will undoubtably consider the characteristics of the entire alignment. Consequently, a soft-ground shield will probably be discarded in favor of a technique capable of excavating the range of in situ materials.

Soft Ground Below the Water Table

The problem of keeping the water out of the underground structures while they are being built has been addressed in a number of ways over the years. In many cases, water flowing into rock excavations is not a significant safety hazard to men or to the excavation, though it may slow the work and thus raise costs. In soft ground materials, however, the inflow of water could bring with it particles of the ground, cause piping, and thus erode or even collapse the excavation.

In tunnels, the inflow of water and associated erosion of the ground can be extremely dangerous and it must be controlled. Compressed air has been used for more than one hundred years to keep water from flowing into the tunnel excavations. The air pressure is designed to equal the outside water pressure, holding it in equilibrium and thus preventing the water from entering the works. The deeper the water, the higher the required air pressure, which eventually results in adverse working conditions with potential health hazards.

Other methods of controlling water inflow into soft-ground tunnels have been used. Barriers to prevent water infiltration have been constructed of various grouts, slurry, frozen ground, and other materials. In recent years, several types of TBMs, designed specifically for tunneling below the water table, have been developed. These are referred to as slurry-shield and earth-pressure-balance machines.

The Hotel Street Subway will be principally located beneath the water table.

5.3.3 Tunneling Methods

The appropriate methods of tunneling in the Hotel Street underground environment are discussed in this section.

Slurry Shield

The Slurry Shield is a TBM designed to work in soft-ground below the water table. It is a closed-face, fully enclosed TBM. As the Slurry Shield is forced ahead into the ground by jacks, the rotating cutter head, fitted with cutting tools, cuts, grinds, and excavates the ground materials. As the Slurry Shield advances, a slurry of bentonite is automatically mixed with the ground just ahead of the cutter head. This bentonite slurry enters the ground materials under an appropriately designed pressure and forms an impervious "cake" which resists the groundwater pressure.

The slurry shield TBM is highly mechanized and typically computerized. Because the men never see the ground, they must rely on instruments to determine the amount of materials being excavated; too much material excavated per foot of advance would result in excessive settlement at the ground surface. Bentonite slurry is expensive, therefore, it is separated and recycled for continued use. Bentonite reclamation facilities are located on the ground surface at regular intervals along the route for this purpose.

Earth Pressure Balance (EPB) Shield

The Earth Pressure Balance (EPB) Shield is a variation of the slurry shield. The men work inside the protection of the EPB shield, operating the TBM and erecting the support system. The rotating EPB cutter head, fitted with appropriate cutters, is jacked into the ground and excavates it. However, instead of using a slurry made of bentonite to resist the groundwater, a slurry made of the earth and water actually encountered at the face is mixed inside a pressurized chamber. This mixture of the earth and water is carefully monitored by various instruments, and is kept at the necessary pressure and density inside the pressurized chamber to resist the outside soil and groundwater pressure. The material is discharged without loss of pressure by a screw conveyor, which is synchronized to the advance of the shield. No cleaning and/or recycling of the earth mixture is needed.

The excavated volume and the discharge volume must be the same. To achieve this, the advance of the EPB shield is controlled either by monitoring the discharged muck volume, and/or by monitoring the earth pressure of the face. Earth pressure within the pressure chamber is controlled by observing the thrust of the shield jacks, torque and revolving speed of the cutter frame and the torque and revolving speed of the screw conveyor.

The EPB shield, or the slurry shield, can be mounted with disc cutters, for hard-rock excavation as well as being mounted with conventional soft ground ripper and rake teeth. These hard-rock cutters can be inserted from inside the TBM. Using high jacking pressures, modern EPB TBMs can cut through very hard rock such as the basalts that might occasionally be found in the Hotel Street Subway as well as soft ground below the water table.

Modern TBMs can be designed to cut through unseen obstacles such as wood or concrete piles. Tie-backs, which may be encountered, or large boulders may be handled by a special operation that entails pressurizing a small area in front of the TBM, allowing a miner to exit and work in the face ahead of the TBM to remove obstacles by hand.

Extruded Liner EPB Shield

An Extruded Liner EPB Shield machine is a variation of the standard EPB shield, which extrudes a freshly-poured concrete lining as it advances. The concrete lining is reinforced with steel fibers that are mixed directly into the concrete. This innovative EPB machine may not be suitable in the Honolulu corals due to the possibility of losing significant volumes of concrete into the voided corals.

"Figure 8" EPB Shield

The "Figure 8" EPB Shield is a new and relatively uncommon shield machine built in the shape of a "Figure 8" devised to excavate two overlapping tunnels at once. The tunnels can be aligned either vertically or horizontally. A specially shaped "Figure 8" precast concrete lining is assembled within the shield. The high capital cost of this machine must be evaluated in conjunction with any savings associated with reduced right-of-way needs.

The "Figure 8" EPB Shield may also exhibit advantages related to the extent or width of associated ground disturbance due to its narrow cross section. However, full advantage of this tunneling machine may not be realized when the geometric requirements of passenger stations are considered. In Hotel Street, the station configuration would require a radical transition in track centerlines before entering a center-platform station or significant land acquisition to accommodate standard side-platform stations. The advantages of using this machine in a vertically stacked alignment, as opposed to independent mined tunnels, may be diminished after considering limitations imposed upon the structural cross section of a vertically stacked station.

Compressed Air Tunneling

Compressed-air tunnel construction is an old technique that relies on a pressurized environment to resist groundwater inflow.

The compressed air pressure is designed to equalize the groundwater pressure and thus prevent water from infiltrating the tunnel excavation. The compressed air also serves to drive groundwater out of the soil adjacent to the excavation, thus, stabilizing and improving the properties of most soils to a significant degree. However, if the required air pressure exceeds about 12 psi gage, negative health effects begin to occur, and the length of work shifts are restricted.

Generally, in compressed-air tunneling, men work inside an open shield and excavate the tunnel by hand mining. Usually, they erect a continuous support system inside the shield and advance the tunnel using jacks. The face of the shield is open, and the ground can be viewed during construction, which can be advantageous when obstacles such as boulders or tiebacks are encountered.

Tunnels below the water table have been built using compressed air without a shield. For example, the New Austrian Tunneling Method stabilizes soil with shotcrete shortly after excavation.

Compressed-air tunneling involves a risk of physical injury, surface settlement, tunnel collapse, or existing building damage when groundwater, soil, or both enter the excavation in the event of a system failure.

The risk in compressed-air tunneling is that the men are exposed directly to the ground, and if there is a failure of the system, the men can be harmed by the entry of groundwater, or soil, or both.

A rapid inflow of soil and water can also occur if the air pressure inadvertently exceeds that necessary to balance the inward groundwater pressure. In such a case, a "blowout" can occur, where the compressed air escapes through a path away from the tunnel. Voids in coral or basalt, gravel beds, abandoned wells or shafts, wooden piles, or soft muds on a stream bottom, could promote blowouts. Because the compressed-air systems are unable to perform properly when large amounts of air are escaping, blowouts are rapidly followed by inflows of soil and water.

Along the Hotel Street alignment, the compressed-air tunneling method appears to have limited applications. It may be suitable for shorter tunnels within the specific problem areas, or for unique arrangements such as personnel cross passages located between running tunnels.

New Austrian Tunneling Method (NATM)

The New Austrian Tunneling Method (NATM) pioneered in the 1930s basically involves a ground excavation method that is promptly stabilized with shotcrete and typically relies on the ground strength for permanent tunnel support. In theory, the thin shotcrete layer prevents small fallouts and unravelling, and the mass of in situ rock or ground subsequently supports itself by arch action within the ground mass.

NATM was first used in rock tunnels, and usually rock bolts were installed with the shotcrete for support. Initially, the drill-and-blast method was used in the excavation of rock tunnels. However, in recent years NATM has been applied successfully to soft-ground conditions. The excavation is made carefully with shotcrete applied promptly, and generally tunnel progress is relatively slow. However, by quickly supporting the excavation, settlement is kept to a minimum and tunneling close to sensitive structures has been successfully completed using NATM.

The natural water table elevation is a serious disadvantage when considering NATM for the Hotel Street Subway tunnel. To adhere, shotcrete must be applied to a nearly-dry ground surface. The

NATM can be used with compressed air, but the previously noted, undesirable characteristics of compressed air would be present.

Dewatering with deep wells along the tunnel route may be a viable method to control groundwater in conjunction with NATM. However, the cost of installing the deep wells and the resulting lowering of the groundwater level with possible ground settlement problems makes this method unattractive.

5.3.4 Tunnel Configurations

A number of configurations are possible with mined tunnels, each possessing characteristics that are advantageous to a specific tunneling environment. In many cases the most pertinent problem is tunneling-induced surface settlement or ground displacement, particularly when it influences the foundations or support systems for existing structures. Ground lost into a tunnel during excavation causes the ground immediately above the tunnel to rearrange itself, and the rearrangement quickly migrates up to the ground surface at an angle which varies with the soil type. This creates a "settlement trough" that can distort and damage nearby structures. Even the best tunneling methods will result in approximately 2 percent "lost ground" (i.e., 102 percent of the theoretical volume has been in fact excavated).

A discussion of several possible tunnel configurations and their applicability to the Hotel Street Subway is addressed below.

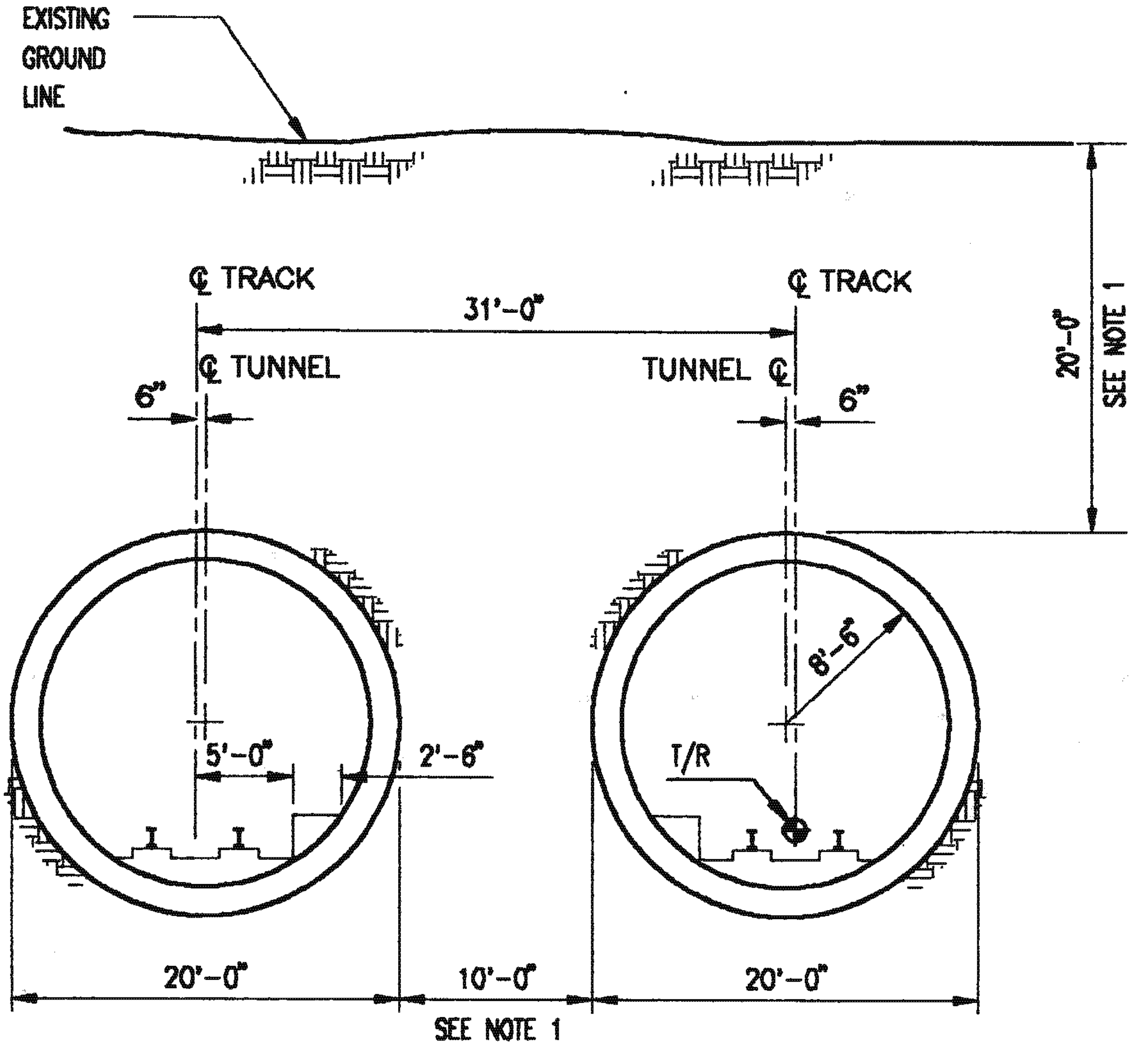
Twin Circular Tunnels

A common configuration for subway tunnels is two identical tunnels placed side by side, as indicated in Sketch 5.3. These tunnels are typically excavated with TBMs and supported by segmental liners.

Measurements have been made of ground movements and settlement in soft ground for a large number of such circular tunnels, above and below the water table. The first tunnel to pass a given point causes an initial settlement trough at the ground surface. The effect of the second tunnel later being excavated near the first is complex: the ground is once again rearranged. The "pillar width" or distance between the two tunnels is an important factor. Approximately speaking, for uncemented sands below the water table, the settlement trough at the ground surface may be estimated extending a line 45 degrees upward from the tunnel springline. Thus, the settlement trough induced by a tunnel 80 feet below the surface would be about eighty feet wide on either side of the tunnels. Structures within the settlement trough might be subject to varying levels of displacement and/or distress.

Twin Circular Tunnels (Stacked Configuration)

The vertically stacked, twin circular tunnel is generally used only within a restrictive right-of-way. Sketch 5.4 illustrates this tunnel configuration, which again is typically constructed with a TBM.

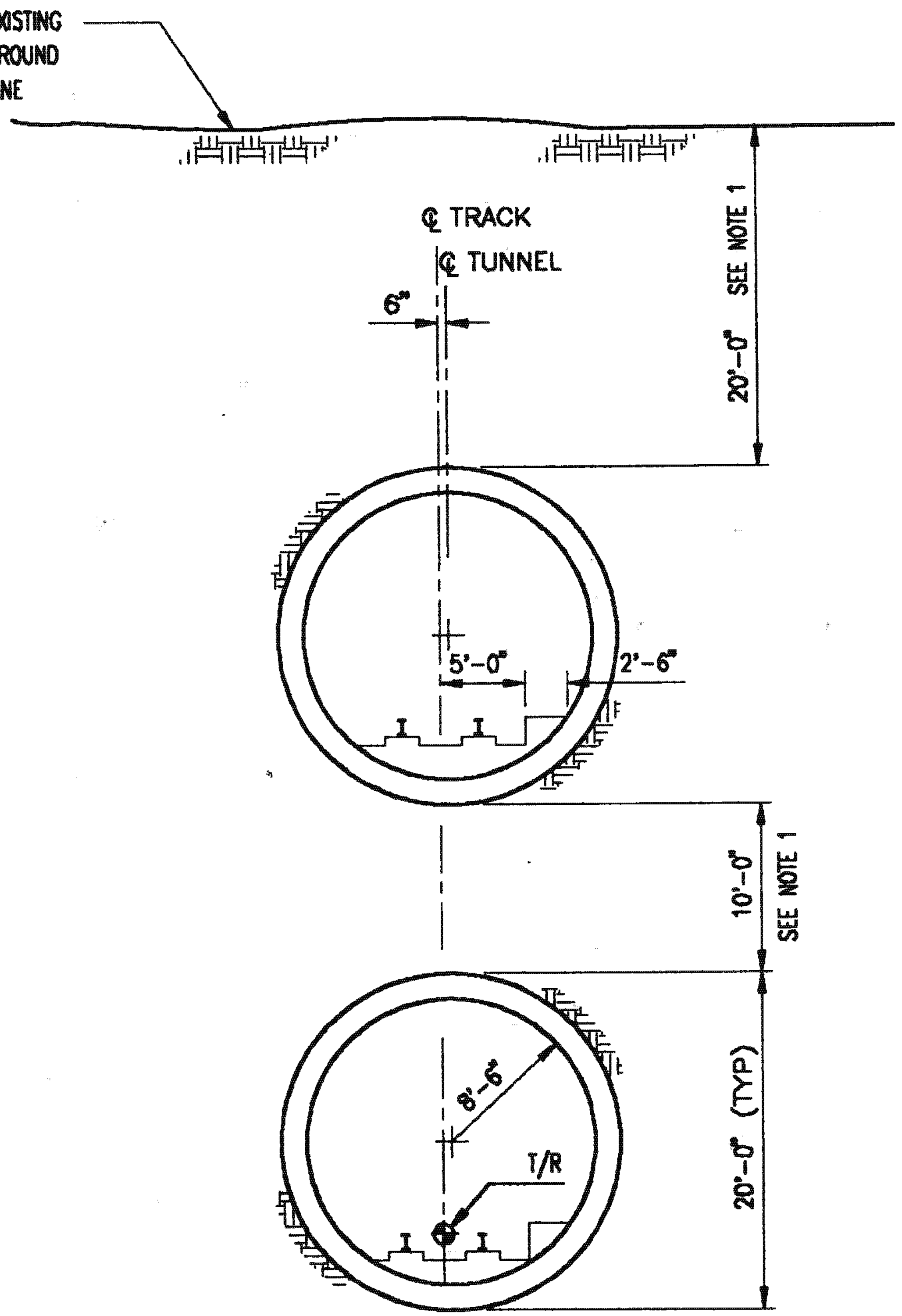


SKETCH 5.3 – TWIN CIRCULAR TUNNELS

NTS

NOTES: 1. DIMENSION VARIES. THE INDICATED DIMENSION IS THE PREFERRED MINIMUM VALUE FOR CLEAR COVER REQUIREMENTS.

2. T/R = TOP OF RAIL



SKETCH 5.4 – TWIN CIRCULAR TUNNELS (STACKED CONFIGURATION)

NTS

NOTES: 1. DIMENSION VARIES. THE INDICATED DIMENSION IS THE PREFERRED MINIMUM VALUE FOR CLEAR COVER REQUIREMENTS.

2. T/R = TOP OF RAIL

The settlement trough for two vertically stacked, twin circular tunnels is expected to be both wider and deeper than a standard side-by-side configuration. The lower tunnel is usually excavated first, and because the lower tunnel is relatively deep, its settlement trough is very wide. Subsequently, the upper tunnel is constructed and causes a complex rearrangement of the ground and superposition of a second settlement trough upon the first.

Single Circular Tunnel (Dual Track)

Sketch 5.5 depicts a large single circular tunnel with sufficient cross-sectional area to house both guideway tracks.

A single large tunnel has the advantage of simplifying some of the structural and geometric complexities associated with individually mined tunnels. Conversely, this tunnel section would require a greater total volume of excavation, additional and larger structural lining elements, potentially produce increased magnitudes of surface settlement, and typically necessitate a lower vertical profile.

Twin Horseshoe Tunnels

Sketch 5.6 illustrates twin horseshoe-shaped tunnels that are frequently used for subways constructed by NATM.

Ground displacement and settlement troughs would share characteristics similar to the TBM constructed, twin circular tunnels. The magnitude of settlement would correlate closely with both the selected construction sequence and the applied standards of construction quality.
NATM does require a moderately dry ground surface to successfully apply shotcrete. The Hotel Street Subway tunnels are well below the water table, and unless the groundwater inflow was stabilized, NATM would be impossible to construct.

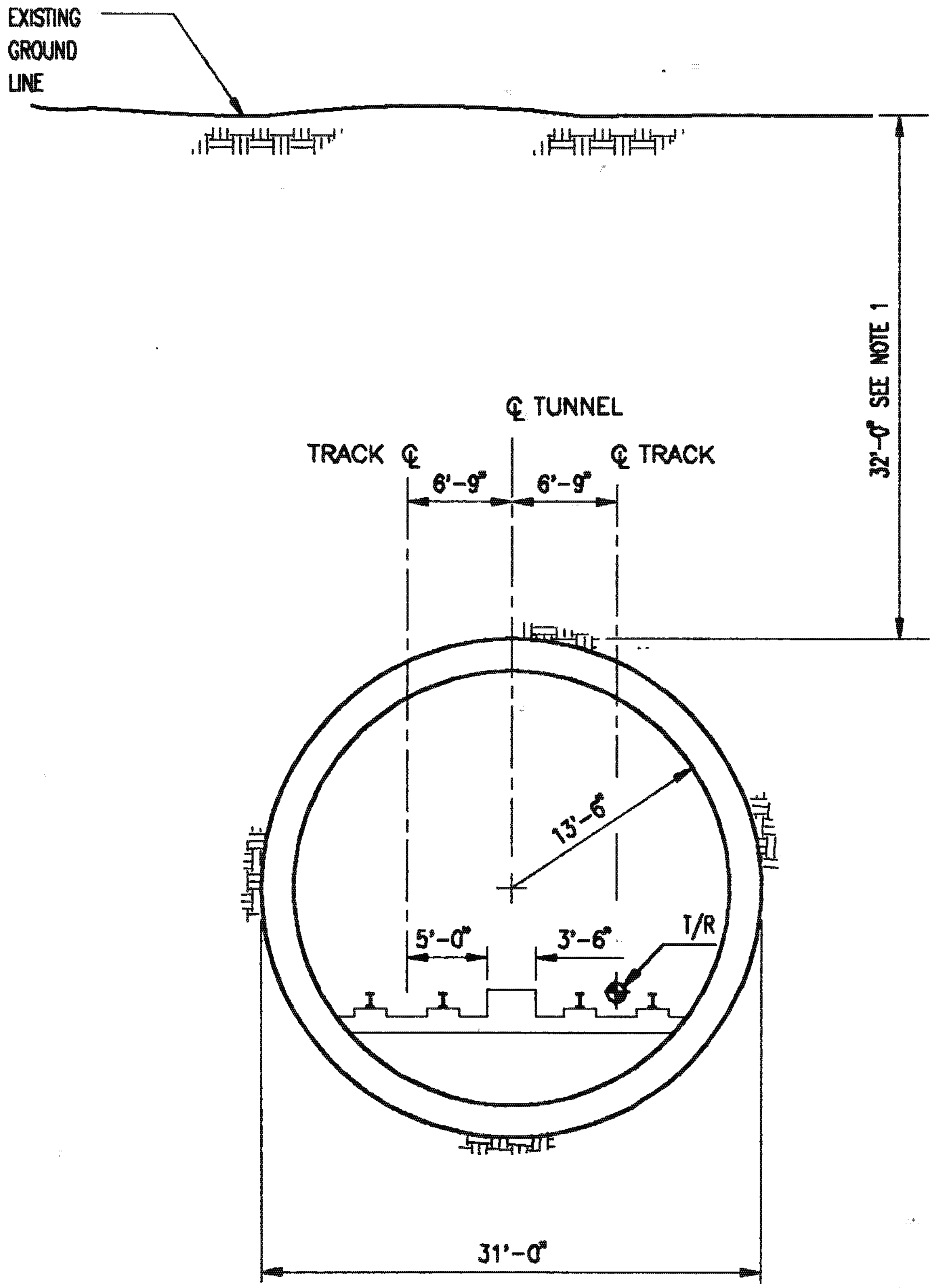
Single Horseshoe Tunnel (Dual Track)

A single horseshoe tunnel, as shown in Sketch 5.7, could be constructed using NATM. This tunnel would have an advantage over the single circular tunnel because the NATM cross section could be customized to match the actual system space requirements thus minimizing the degree of over excavation.

The application of this configuration would be contingent upon overcoming the remaining disadvantage characteristic of the single large excavation as well as surmounting the groundwater problem associated with NATM construction.

"Figure 8" Tunnels

The "Figure 8" tunnels are depicted in Sketches 5.8 and 5.9 for the side-by-side and vertically stacked configurations, respectively. The pillar width (distance between tunnels) for both

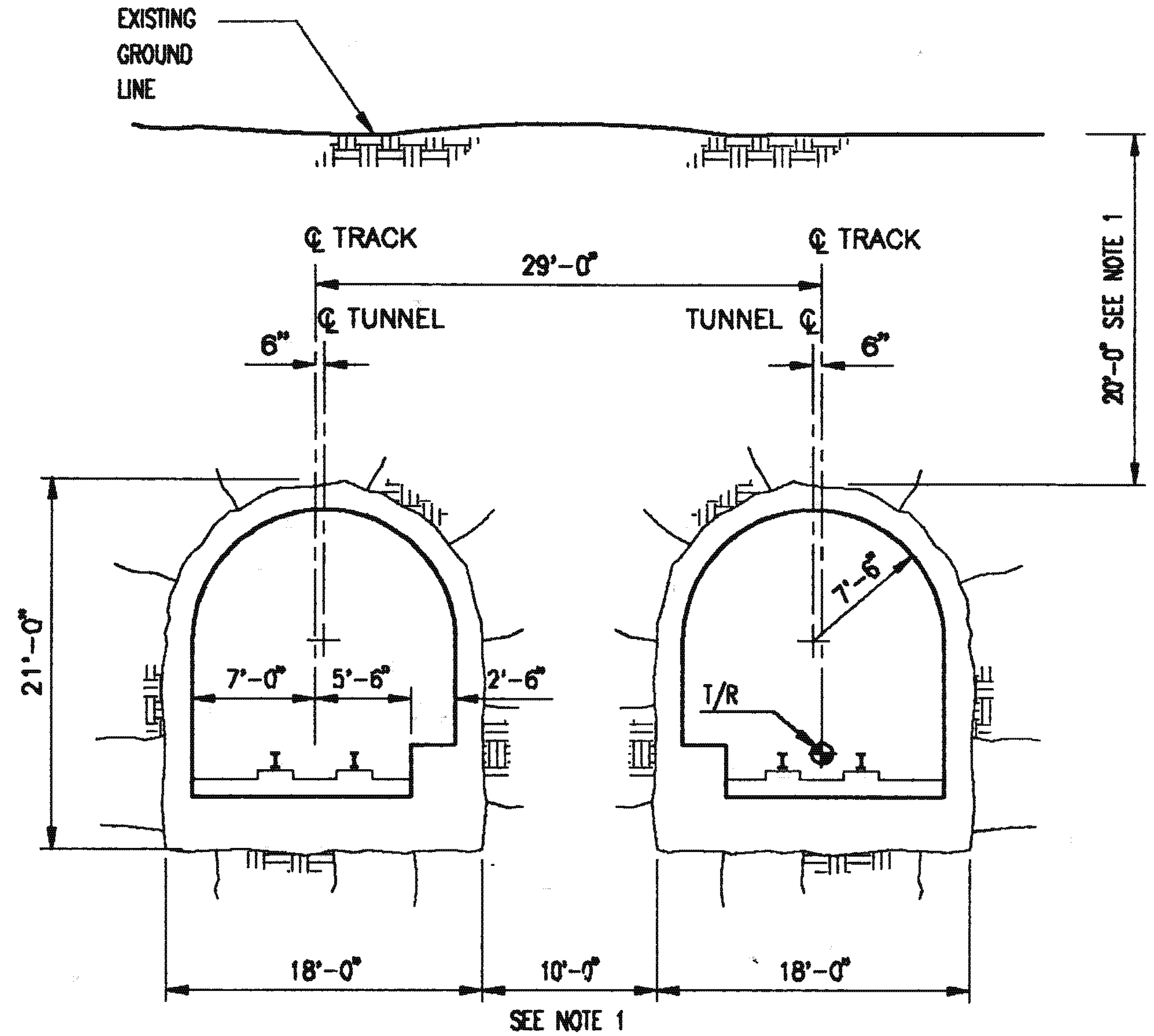


SKETCH 5.5 – SINGLE CIRCULAR TUNNEL (DUAL TRACK)

NTS

NOTES: 1. DIMENSION VARIES. THE INDICATED DIMENSION IS THE PREFERRED MINIMUM VALUE FOR CLEAR COVER REQUIREMENTS.

2. T/R = TOP OF RAIL

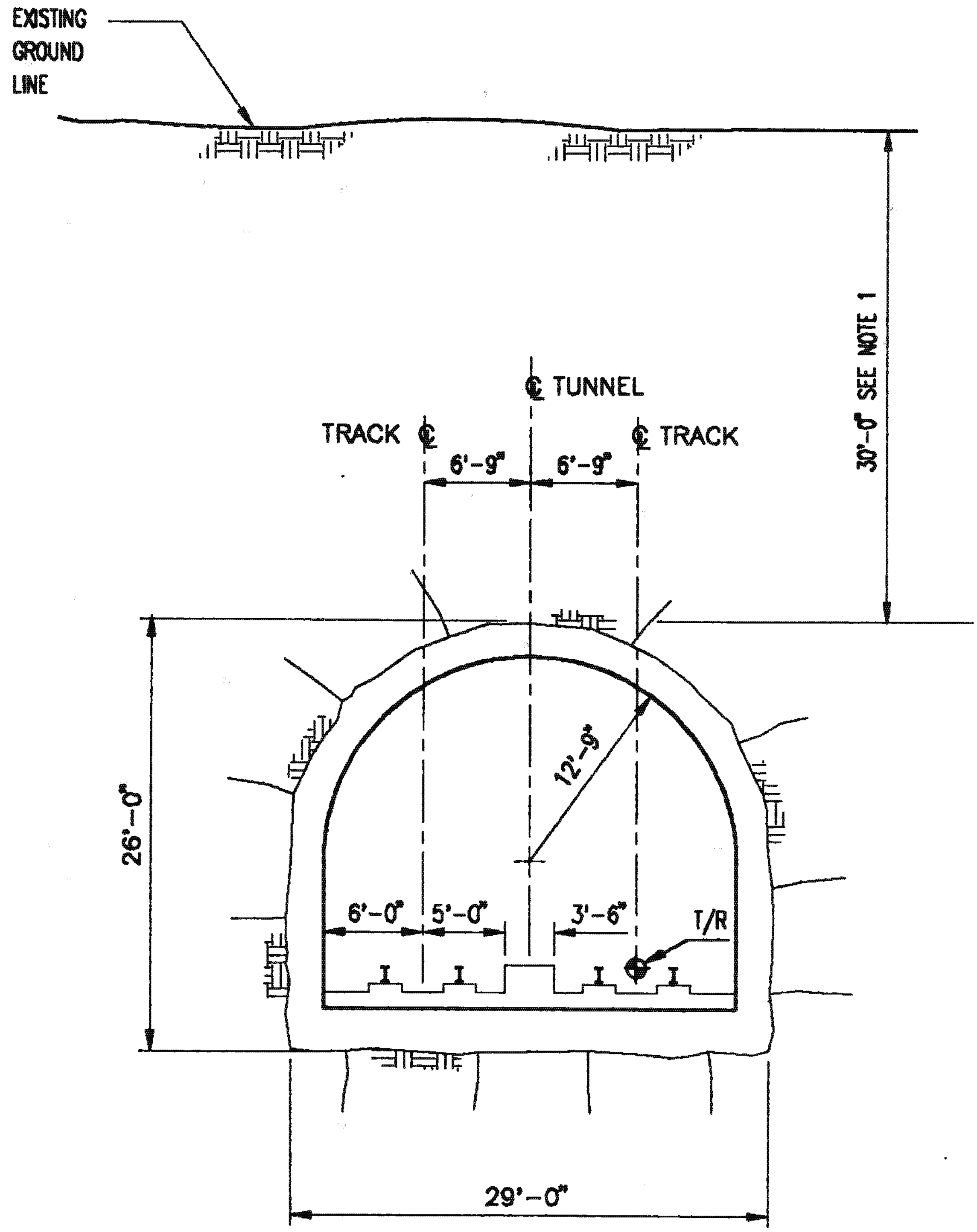


SKETCH 5.6 – TWIN HORSESHOE TUNNELS

NTS

NOTES: 1. DIMENSION VARIES. THE INDICATED DIMENSION IS THE PREFERRED MINIMUM VALUE FOR CLEAR COVER REQUIREMENTS.

2. T/R = TOP OF RAIL

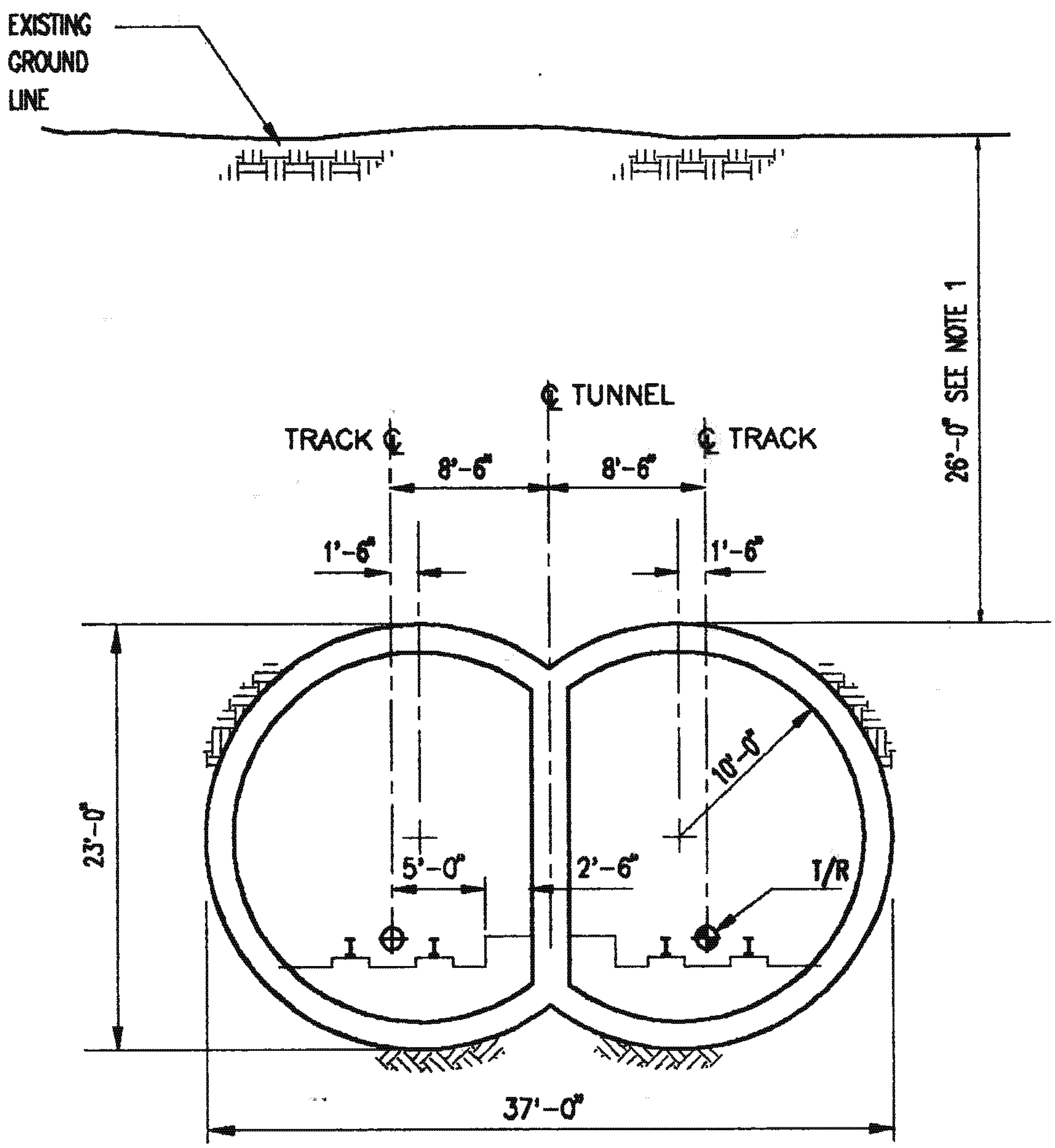


SKETCH 5.7 – SINGLE HORSESHOE TUNNEL (DUAL TRACK)

NTS

NOTES: 1. DIMENSION VARIES. THE INDICATED DIMENSION IS THE PREFERRED MINIMUM VALUE FOR CLEAR COVER REQUIREMENTS.

2. T/R = TOP OF RAIL

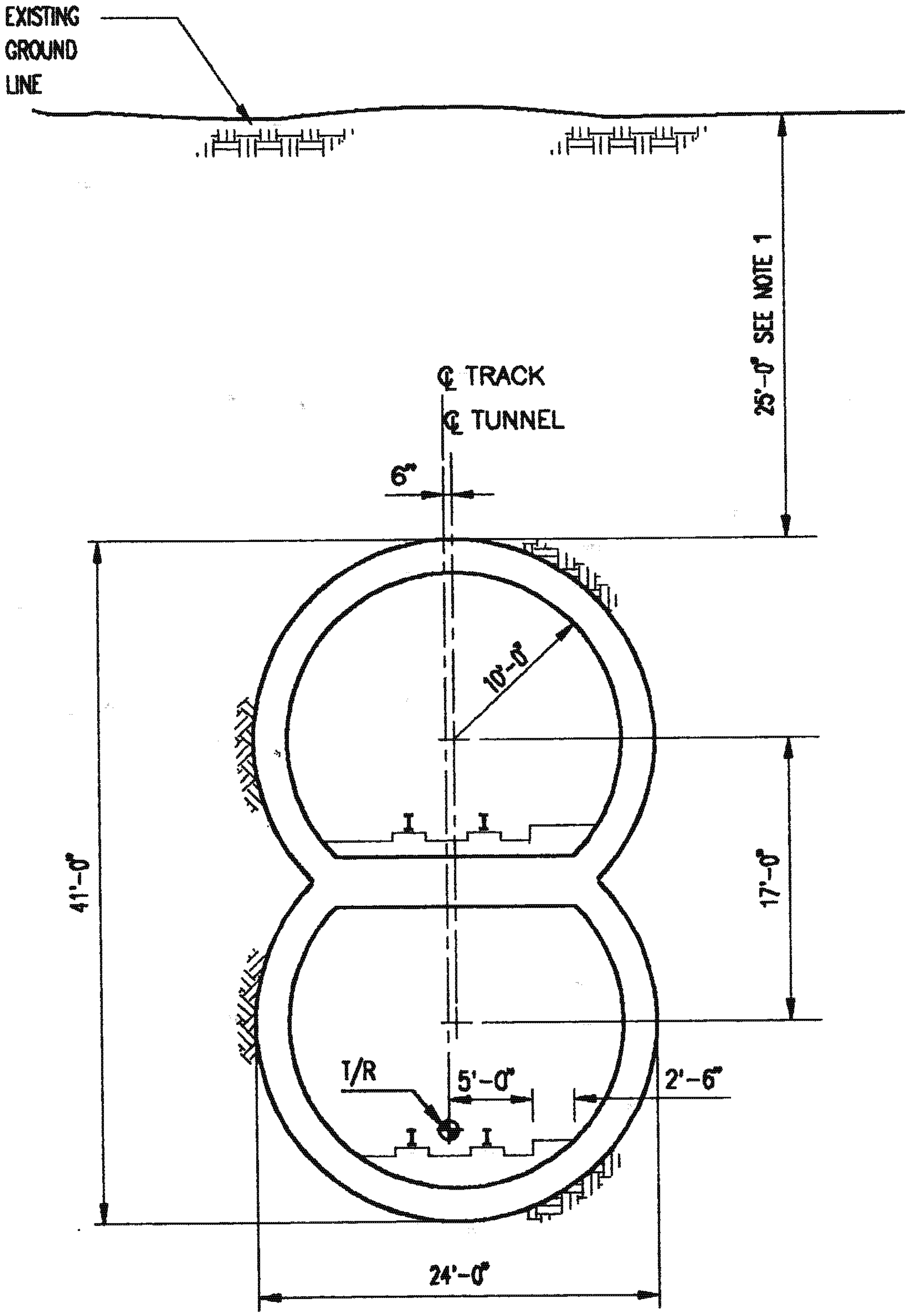


SKETCH 5.8 – "FIGURE 8" TUNNEL

NTS

NOTES: 1. DIMENSION VARIES. THE INDICATED DIMENSION IS THE PREFERRED MINIMUM VALUE FOR CLEAR COVER REQUIREMENTS.

2. T/R = TOP OF RAIL



SKETCH 5.9 – "FIGURE 8" TUNNEL (STACKED CONFIGURATION)

NTS

NOTES: 1. DIMENSION VARIES. THE INDICATED DIMENSION IS THE PREFERRED MINIMUM VALUE FOR CLEAR COVER REQUIREMENTS.

2. T/R = TOP OF RAIL

orientations is kept to a minimum; however, the pillar located between the vertically stacked tunnels must be designed to support train live load.

A "Figure 8" earth-pressure-balance tunnel boring machine would excavate for the twin tracks in a single pass. It is expected that surface settlements may be less for a successfully driven "Figure 8" tunnel than for a side-by-side, vertically stacked, or large single-bore tunnel.

This tunneling method is at a disadvantage at locations where transition sections are required by alignment. All of the feasible Hotel Street Subway stations require alignment transitions. Additionally, the "Figure 8" TBM is a relatively new technology with limited sources of procurement.

5.3.5 Concerns

Groundwater

The Hotel Street Subway alignment is located well below sea level and the coincident water table. Various soft-ground materials, including lagoon deposits, alluvial sands, silts, clays, and corals, with various degrees of cementation are all found within the alignment. In addition, isolated outcrops of basalt may be encountered. Tunneling in the soft grounds is made complex by the presence of groundwater.

During tunnel construction and service operation, it is imperative that the groundwater inflow be controlled. Even slow inflow of groundwater can cause piping and migration of fines into the tunnel, inducing very large surface settlements. Rapid water inflow into tunnels could be catastrophic. The design of the tunnel lining must insure permanent watertightness; some projects have failed when fine soils migrated into the tunnel in large quantities through the lining joints because of groundwater action. The resulting irregular voids may expose the tunnel lining to unbalanced loads that greatly exceed the ordinary design parameters.

Surface Settlement

Tunneling in soft ground invariably results in some "ground loss" or over-excavation beyond the theoretical volume that causes a collapse and rearrangement of the ground particles. This in turn produces a settlement trough above the excavation. In metropolitan areas, this surface settlement can cause disruption of streets, utilities, and building structures. Adjacent buildings or structures may require protection to avoid damage due to this settlement.

As tunnels are advanced in soft ground, ground loss occurs due to several practical problems. TBMs are advanced in a series of discreet "shoves" of 3 to 6 feet at a time, and if the TBM is misaligned, there will be overexcavation. The support system must be assembled, moved out of the shield, erected, and grouted into place. The TBM shield, of course, initially excavates a tunnel of larger diameter than the support system, and there may be ground loss before the voids behind the support system can be grouted. If an open-faced TBM is employed, and the ground is not firm, some ravelling and fallout may occur at the face. All of the separate sources of "lost ground" are heavily influenced by the construction procedure, experience, and skill of the workmen, but some loss is inevitable. Successful tunneling results in excess lost ground amounting to about 2 percent of the excavated volume. Poor tunneling technique can result in 5 percent lost ground.

This ground loss at the tunnel causes a rearrangement of the ground above the tunnel. Measurements made at many soft-ground tunnels indicate that the surface of the ground will settle an amount whose volume is approximately equal to the volume of the "lost ground" overexcavated and/or lost at tunnel depth.

An empirical approach exists, based on field evidence that is commonly used to estimate the configuration of the settlement trough at the ground surface above the excavation of the tunnel. However, the predicted rearrangement of the ground becomes quite complex when a second tunnel is excavated in the vicinity of a previously bored tunnel.

Dewatering may cause a consolidation of soft, fine-grained sediments, which is an additional source of settlement. Most of the soft ground along the subway alignment is granular (coralline sands, gravels, and cemented coral) and, thus, not subject to consolidation. Fine-grained alluvial silt and clay sediments do exist at relatively deep elevations and their consolidation could introduce additional displacements. In isolated locations fine sediments, susceptible to consolidation, are found near the ground surface.

A settlement trough generated by tunneling through open country will generally go unnoticed with no objection or adverse consequence. In urban areas, the settlement trough may extend below buildings, and the resulting displacements can cause architectural or structural damage to existing buildings. Prudent owners of tunnels perform preconstruction surveys, make detailed photographs of the adjacent buildings, and implement sophisticated monitoring programs during construction to provide historical documentation of actual or perceived changes. In many legitimate cases settlement damage during tunneling must be acknowledged and remedied.

There are numerous well-cemented coral beds along the route of the Hotel Street Subway. Experience with similar conditions indicates that these beds will suffer negligible settlement. However, these coral beds are not continuous, and so at irregular intervals uncemented materials will be found that will undergo some settlement. The actual settlement is highly unpredictable. Logically, a monitoring system designed to measure actual settlement and possible building distress would be installed.

Geotechnical instrumentation to monitor ground movement and especially ground settlement, is an essential part of ground control in tunneling and subway station excavation. Geotechnical measuring instruments can be read so promptly that the tunnel or cut-and-cover excavation techniques can be modified or even halted if necessary, within a matter of minutes. Remedial measures for excessive settlement or other hazardous ground movement must be tailor-made for the particular problem, but cement or chemical grouting, "compaction" grouting, and other techniques are well known and can be used.

5.4 Portal Structures

5.4.1 Introduction

The guideway alignment will transition below grade and reemerge within the Hotel Street Subway project limits. Portal structures will support the transition from surface to below-grade tunnels.

5.4.2 Configuration

Tunnel portals are generally composed of a length of open-cut or retaining-wall structure followed by the actual tunnel entrance. The length of retained cut is typically a function of the running surface grade and the surrounding ground contours. The portal entrance is frequently followed by a transition structure that supports the shallow or relatively unstable ground near the tunnel entrance. The transition structure commonly consists of a cut-and-cover box structure that terminates at a location where the overburden is suitable to support the designed tunnel section.

Design solutions for the tunnel entrance and associated portal geometry must consider the dynamics of a train passing in and out of the tunnel. Tunnel portals are designed to minimize the rate-of-change of air pressure of a train passing through the portal. Attenuation or sudden changes in air pressure and noise levels should be avoided. Pressure rise is a function of the cross-sectional area of the portal entrance and the velocity of the passing train. Design solutions may entail flared portals or a series of perforations along the interior wall of a double-cell box.

Portal structures are configured to match the tunnel geometry and retain the surrounding embankments. The associated retaining structures typically consist of either U-wall sections, where both vertical walls are continuous with a full-width base slab, or alternately a section composed of individual retaining walls.

In designing the location of portal structures and termination of U-wall sections, the potential of flooding resulting from high water levels near bodies of water and tributary watercourses or from local storm runoff must be considered. Provisions should also be made for immediate and effective removal of water from rainfall, drainage, groundwater seepage, or any other source. Where applicable, the design must resist hydrostatic uplift.

5.4.3 Construction Methods

Tunnel portals are typically constructed using methods similar to those used for cut-and-cover construction as described in Section 5.2.3. The general procedures include installation of an earth-retaining system, excavation and bracing, followed by construction of the permanent structure. The only unique operation would possibly entail the stabilization of the ground around the actual tunnel portal.

The associated U-wall sections may be built using either an open- or retained-cut construction method. Open-cut construction would require a relatively wide right-of-way or construction easement because the excavation width is a function of slope stability and the depth of construction gradually increases near the portal. There are right-of-way restrictions and physical constraints near the Hotel Street Subway portals that limit the feasibility of pursuing open-cut construction. U-walls installed using retained-cut methods could be constructed adjacent to temporary sheet piles or as a diaphragm wall designed for temporary and permanent conditions.

The estimated groundwater elevation suggests that some dewatering will be required under any construction scenario. The implications of dewatering and associated merits of each construction scheme are similar to those cited for cut-and-cover construction.

5.5 Conclusion

The method used to construct the Hotel Street Subway essentially pivots on the decision to utilize either the cut-and-cover or the bored tunnel techniques. For Hotel Street, either system could be used. Each has respective advantages and disadvantages as detailed in Sections 5.2 and 5.3, but both techniques will provide a permanent facility that will perform with equivalent levels of satisfaction.

To minimize disruption to surface activities during the construction of the transit system, particularly in the downtown commercial district and the Capital Special District, cut-and-cover construction should be avoided. For this reason, where applicable, the order-of-magnitude cost estimate in Section 7.8 was based on a suitable bored tunnel construction method, which is generally less disruptive than cut-and-cover construction methods.

Section 5.3.3 describes several appropriate methods of tunneling in the Hotel Street underground environment. They include Slurry Shield, Earth Pressure Balance (EPB) Shield, Extruded Liner EPB Shield, "Figure 8" EPB Shield, Compressed Air Tunneling, and the New Austrian Tunneling Method (NATM). Evaluated as a group, these construction methods can yield a variety of tunnel configurations with individual characteristics that must be analyzed relative to the Hotel Street underground environment. The tunnel configurations examined for the Hotel Street Subway included Twin Circular Tunnels, Twin Circular Tunnels (Stacked Configuration), Single Circular Tunnel (Dual Track), Twin Horseshoe Tunnels, Single Horseshoe Tunnel (Dual Track), and "Figure 8" Tunnels. All of the identified schemes are feasible for Hotel Street; however, based on the limited available data one method was selected as being most appropriate, and used for deriving the order of magnitude cost estimate.

The overriding criteria that governed conceptual selection of the tunneling technique involved ground subsidence and ground water control. The operating characteristics of the Earth Pressure Balance (EPB) Shield appears to be most suitable in responding to these critical criteria. The EPB Shield uses excavated ground within a sealed chamber to balance the inflow of ground water. The EPB machine is highly mechanized and can effectively advance a tunnel through a number of geologic conditions including unforeseen obstacles such as wood or concrete piles. It has an advantage over a Slurry Shield which functions in a similar fashion, but requires a large bentonite reclamation plant on the ground surface. As detailed in Section 5.3.3, the other identified tunneling methods have additional disadvantages that detract from their virtues.

Ground displacement is closely related to the geometric configuration of the proposed tunnel and the quality of construction (extent of overexcavation) that can be expected from the proposed construction technique. Each of the tunnel configurations were studied within the context of the Hotel Street environment and a conceptual assessment indicated that the twin circular tunnels would be the most appropriate solution. The circular tunnels are compatible with the EPB Shield technology, they accommodate the alignment constraints and each of the dual tunnels is relatively small in cross section, thereby reducing the potential for large ground displacements.

Portal structures provide guideway transitions between the aerial and underground alignments. Standard tunneling techniques generally require a minimum overburden to preclude a cave-in scenario. At the portal locations the overburden requirements generally cannot be achieved, so construction usually reverts to the cut-and-cover method. This is the expected choice for Hotel Street, and a traditional retained cut construction method is anticipated. The existing soil conditions and congested nature adjacent to the work site, encourage the selection of diaphragm wall construction. Diaphragm walls have the advantage of effectively controlling ground displacements thereby minimizing the potential of inducing structural building damage.

6. UNDERGROUND STATIONS

6.1 Introduction

Three underground stations are proposed within the *Hotel Street Subway Study* area:

- Hotel/Bethel
- Hotel/Alakea
- Civic Center

Two of the stations, Hotel/Bethel and Hotel/Alakea, are projected to be among the highest patronage stations in the system; 29,000 and 20,900 daily (2005 A.D.), respectively. Both stations are problematic. The stations are situated within Hotel Street's 50-foot-wide right-of-way and are constrained by alignment horizontal and vertical curve requirements. In addition, geological conditions and associated cost considerations preclude the use of station configurations that utilize below-grade ticketing concourses or mezzanines within the street right-of-way.

The third station, Civic Center, is not constrained by a narrow right-of-way. A conventional station configuration, consisting of a center platform with mezzanine, is therefore possible. The mezzanines permit a degree of flexibility in locating station entrances. The Civic Center Station is projected to have about 13,400 daily riders in the Year 2005.

For the purposes of this study, three basic station configurations have been examined:

- Center platform

- Side platform

- Stacked platform.

Center- and side-platform stations are generally wider than stacked-platform stations, excluding vertical circulation considerations. Because of Hotel Street's right-of-way constraints and geological conditions addressed in Sections 3 and 4, the stacked-platform configuration was selected as the most viable solution.

6.2 General Considerations

6.2.1 Functional/Spatial Design Considerations

Essential to good station planning, particularly to stations below grade, are basic design criteria that influence a station's configuration and the dimensional requirements for public circulation spaces. These criteria include but are not limited to:

1) Simplicity, clarity, and predictability of path for patrons.

2) Functional commonality between stations.

3) Maximizing patron security and safety by avoiding obstructions, circuitous paths, and blind spots in public areas, particularly at platform level.

4) Providing adequate circulation spaces, particularly surge spaces, based on maximum anticipated patronage.

5) Consolidation of all vertical circulation elements in one area where possible to reinforce items 1 and 3 above, and to minimize CCTV and other security requirements.

6) Locate circulation elements serving platform areas to encourage balanced train loading and unloading.

The functional/spatial requirements of stations generally require significant at-grade facilities called a station house. Emergency exits and ventilation shafts will also be required. Typically, station houses consist of the following elements:

- Station entrance and security closure
- Fare machines and money changers
- System information and map, including information on interfaces with other components of the public transportation system
- Public and system information telephones
- Fare paid zone demarkation
- Vertical circulation elements accessing the platform level.

The vertical circulation elements of grade-separated stations can vary depending on projected patronage, the vertical separation between entry level and platform level, code requirements, and a transit authority's design policies. Vertical circulation includes stairs, escalators, and elevators; with the latter potentially serving the handicapped, people with temporary disabilities, parents with strollers, and patrons intimidated by long escalator runs could access the stations by using the elevators.

With respect to the design policies of a transit authority, some systems only provide escalators in the up direction, particularly in low-patronage stations. Given the high projected patronage for these stations, escalators for both the up and down directions was assumed for the purposes of this study.

6.2.2 Expandability

The future expansion of stations typically focuses on three considerations:

AR00051726

- Extending platforms to accommodate longer trains;
- Enhancing vertical circulation elements (such as replacing stairs with escalators); and
- Accommodating additional station entrances.

The aerial stations of the proposed system are configured with 240-foot-long platforms and are expandable to 320 feet should future requirements so demand. Given the inherent construction- and geometric-related issues associated with extending platforms of underground stations, the three stations of the Hotel Street Subway section will be designed for their ultimate platform length. The final base and ultimate platform lengths will be determined after the operating characteristics of the selected transit system technology is defined.

6.2.3 Contextual Considerations

Two of the three proposed stations — Hotel/Bethel and Hotel/Alakea — are to have their platform areas located within the narrow Hotel Street right-of-way. The majority of existing structures and those currently under construction along Hotel Street are built out to the property line and generally preclude penetration by other structures. Many of the older structures are within the Historic Chinatown Special District, while the newer structures typically include below-grade parking constructed out or near to the property line. Exceptions to the 50-foot-width constraint are the vacant lot at the intersection of Hotel and Maunakea streets, the Chinatown Gateway Park at the intersection of Hotel and Bethel streets, the Fort Street Mall, Union Mall, the Plaza in front of Bishop Square (Hotel and Alakea), and the entrance forecourt to the District Court Building (the Kauikeaouli Hale).

The third station, Civic Center, is sited under the landscaped areas makai of the Municipal Building and the intersection of South King Street, South Street, and Kapiolani Boulevard. Although there are no significant right-of-way issues at this location, existing mature trees and major landscape elements, such as the waterfall and related landscaping on the island at the intersection of the three above-mentioned streets, restrict station entrance options.

6.2.4 Air Conditioning

A preliminary investigation of environmental control systems for the Hotel Street Subway stations has been prepared. Although several alternatives have been evaluated, the primary objective of this study was to determine whether mechanical cooling (air conditioning) would be required.

In Honolulu, during the afternoon on an average summer day, the normal temperature during the P.M. peak period, based upon National Oceanic and Atmospheric Administration (NOAA) data, is about 87 degrees fahrenheit, dry bulb, with a relative humidity of about 60 percent. The system vendor Request for Proposal specified a vehicle environmental control system that can maintain 75 degrees fahrenheit with a relative humidity of 55 percent.

The design of a subway Environmental Control System (ECS) usually considers the Relative Warmth Index (RWI) as a measure of comfort during the summer months. The RWI takes into account the activity of the patron (walking, standing, seated), and the air velocities as well as the air temperature and humidity.

Four ECS options have been evaluated for the Hotel Street Subway stations. They are:

1) Mechanical cooling to achieve a building-type environment (78 degrees F, 55 percent RH) inside a station with platform-edge screen walls.

2) Mechanical cooling to maintain ambient conditions inside the station with platform-edge screen walls.

3) Mechanical cooling to maintain ambient conditions inside a station without platform-edge screens walls.

4) No mechanical cooling but enhanced ventilation.

The following table includes the RWI values for the four ECS alternatives as well as that for a person on the street or in a vehicle. There are variations of these alternatives that would yield different results; however, the table does provide a reasonable range of upper and lower limits. The comparison is based on general principals for estimating heat gains and losses and station airflows. Detailed calculations have not been prepared.

Environmental Control System Alternatives

Alternative: Air Conditioning	Alternative: Platform Screens	Design Temp (deg F.)	Design RH (%)	RWI	Mechanical Cooling (Tons)
1. Yes	Yes	78°	55	0.24	200
2. Yes	Yes	87°	60	0.43	60
3. Yes	No	87°	60	0.32	160
4. No	No	+100°	--	0.85	0
Street Environment (Standing to Walking)		87°	60	0.26 to 0.36	N/A
Train Environment		75°	55	0.26	N/A

Notes:

1. Train heat was determined for a 6-car train carrying 80 passengers per car at a rate of 36 trains per hour (Capacity = 17,250 passengers per hour).

2. Station patronage was based on data provided in the System Request for Proposal (TP Exhibit 5.1-1).

3. Other station heat loads include lighting and escalators. It is assumed that equipment rooms are not vented into the station or tunnels.

As indicated in the table, each alternative provides a different level of patron comfort with an associated cost in terms of equipment and space. Although one alternative has no mechanical cooling but includes enhanced station ventilation, the associated level of comfort is unacceptable. It appears that some level of mechanical cooling will be required for the Hotel Street Subway stations.

6.3 Station Access

Two basic methods of accessing the Hotel Street Subway stations are possible:

- Via existing street right-of-ways or publicly-owned lands; or
- Via existing private property — through acquisition or joint development.

6.3.1 Access Via Public Right-Of-Way

Locating entrances to the Hotel/Bethel and Hotel/Alakea stations within the Hotel Street right-of-way will be problematic. If subterranean ticketing concourses are not employed, typical at-grade station houses for the stations could be as large as 32 feet wide by 73 feet long. Station entrances for center-platform stations without mezzanines could only be located within the Hotel Street right-of-way.

Placement of a typical station house centrally within the right-of-way would leave only nine feet between it and adjacent structures (excluding canopies, signs, or other building projections), a distance too narrow to permit an emergency vehicle access lane on Hotel Street. Off-setting the station house would resolve this problem but could also require off-set of the guideway tunnel for center-platform stations. The shift would be 10 to 12 feet beyond the 50-foot right-of-way.

Two station houses would be required for side-platform stations without mezzanines. These would have to be located outside the Hotel Street right-of-way and each entrance would be approximately 28 to 30 feet wide and about 140 feet long.

For stacked platform stations, a typical station house would be partially or totally outside of the 50-foot right-of-way. Utilizing either the Chinatown Gateway Park or the forecourt to the District Courts Building for a typical station house would be a possibility. However, both of these locations for station entrances are problematic from other standpoints.

An alternative station entrance configuration for a stacked-platform configuration would consist of a two-escalator/stair (side-by-side) element within the street right-of-way and an elevator outside the right-of-way, within private development. The width of the station entrance would thereby be reduced to approximately 21 feet. Such an entrance could be enclosed or open with weather-proofed escalators. The latter would be preferable given the proximity of adjacent buildings. This configuration requires endloading the station platforms.

The Civic Center Station, given its location and the opportunity to provide a mezzanine level, does not present similar difficulties.

6.3.2 Access Via Private Property or Joint Development

Given the difficulties associated with providing station access within the narrow Hotel Street right-of-way, access through existing private property or joint development for stacked- and side-platform station configurations without mezzanines was considered. However, the newer structures along Hotel Street contain several levels of below-grade parking typically constructed to the property line and substantial demolition would be required to accommodate station access structures. Some existing buildings could be utilized for station access, such as the Executive Centre and Pau'ahi Tower. Other opportunities for joint development exist on properties that are vacant, under utilized, or proposed for major redevelopment such as the Campbell Property and the Kekaulike redevelopment project.

The difficulty in providing a mezzanine level for the Hotel/Bethel and Hotel/Alakea stations limits multiple station access through joint development, regardless of station configuration. As discussed previously, a center-platform configuration would require access from the Hotel Street right-of-way. A side-platform station would require access from both sides of Hotel Street and result in an undesireable station configuration (separate entrances for each travel direction). Stacked platform configuration, though limiting station access via joint development to only one side of Hotel Street, does provide the access opportunities that optimize station functional/spatial requirements.

6.4 Alternate Station Configurations

The following illustrations portray prototypical underground station configurations. As stated previously, mezzanine levels for the Hotel/Bethel and Hotel/Alakea stations would be difficult, given geometric and geological conditions. Even if geological conditions were not an issue, a stacked-platform station with mezzanine would require three flights of vertical circulation per access point and would place the lowest platform approximately 77 feet below grade. A mezzanine level is possible for the Civic Center Station and is recommended.

6.4.1 Center-Platform Station — Cut-and-Cover

With a below-grade mezzanine level, multiple access points to a center platform station would be possible, including through adjacent buildings. (See Sketch 6.1) This station type would be applicable for the Civic Center Station where there is adequate right-of-way width for the 56-foot-wide station structure. This station configuration is deemed impractical for the Hotel/Bethel and Hotel/Alakea stations due to the insufficient width of the Hotel Street right-of-way.

6.4.2 Center Platform Station — Mined

A mined center platform station (see Sketch 6.2) would be approximately 53 feet wide, depending on the configuration of the vertical circulation elements, and would therefore project several feet beyond the Hotel Street right-of-way, not including construction tolerances. With no mezzanine, station access would have to be located within the Hotel Street right-of-way.

6.4.3 Side-Platform Station — Cut and Cover

A side-platform station (see Sketch 6.3) would be approximately 57 feet wide, excluding vertical circulation, assuming single-cell tunnel or cut-and-cover construction methods could be used. The vertical circulation elements would add an additional 36 feet to the overall width. As a single-cell tunnel is not being recommended, a side-platform station is not practical.

6.4.4 Stacked Platform Station — Cut and Cover (Sketch 6.4)

A stacked-platform station (see Sketch 6.4) that is end loaded could minimize at-grade station entrance requirements by locating ticketing, system information, and related facilities below grade. Access between the upper and lower platform levels will be problematic with a two escalator/stair element. This element would project approximately 13 feet beyond the Hotel Street right-of-way for a length of approximately 140 feet per entrance. A variation of this type is workable within the 50-foot right-of-way. It consists of two banks of single escalators and stairs units in line rather than side-by-side connecting the two platform levels.

6.5 Construction Methods

6.5.1 Introduction

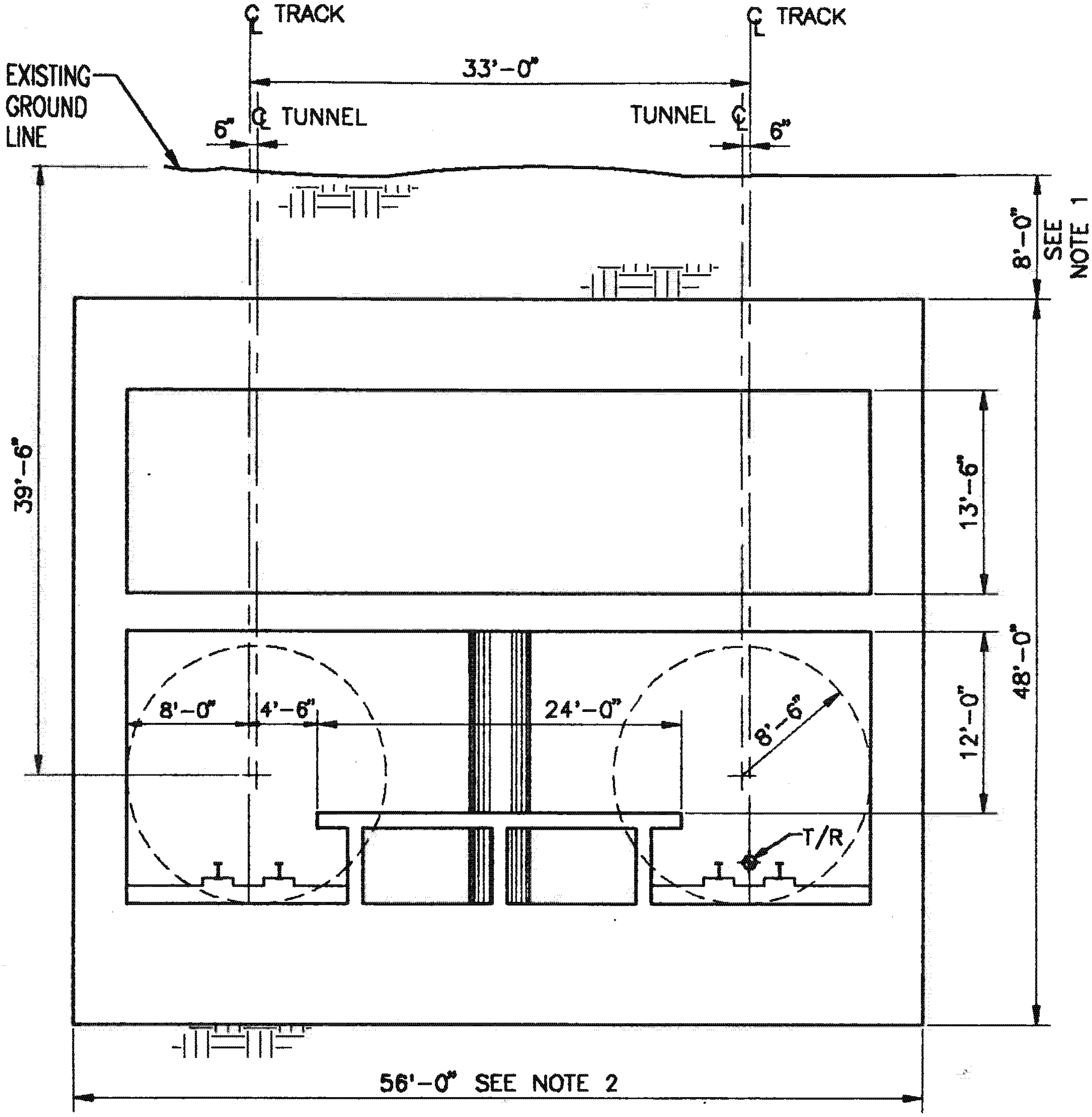
Underground subway stations are typically very large and technically complex structures. Construction generally occurs in the right-of-way of a busy downtown street, typically within an intersection. The contractor is forced to deal with a maze of buried utilities without disrupting service, maintain traffic flow around the construction site, and safeguard the surrounding buildings from damage. In addition, he must minimize the negative impacts of his activities to the neighboring businesses and residences.

In general, two methods of providing an underground space for construction of the station are available to the contractor: a cut-and-cover excavation or a mined-cavern excavation. Both methods have various advantages and disadvantages depending upon the particular conditions involved. This section will provide an overview of each method and discuss the applicability of each to the Hotel Street Subway.

6.5.2 Cut-and-Cover Excavations

Cut-and-cover excavation is the traditional method of underground construction for large structures such as subway stations. It is a relatively straight forward method familiar to many general contractors, utilizing readily available technology.

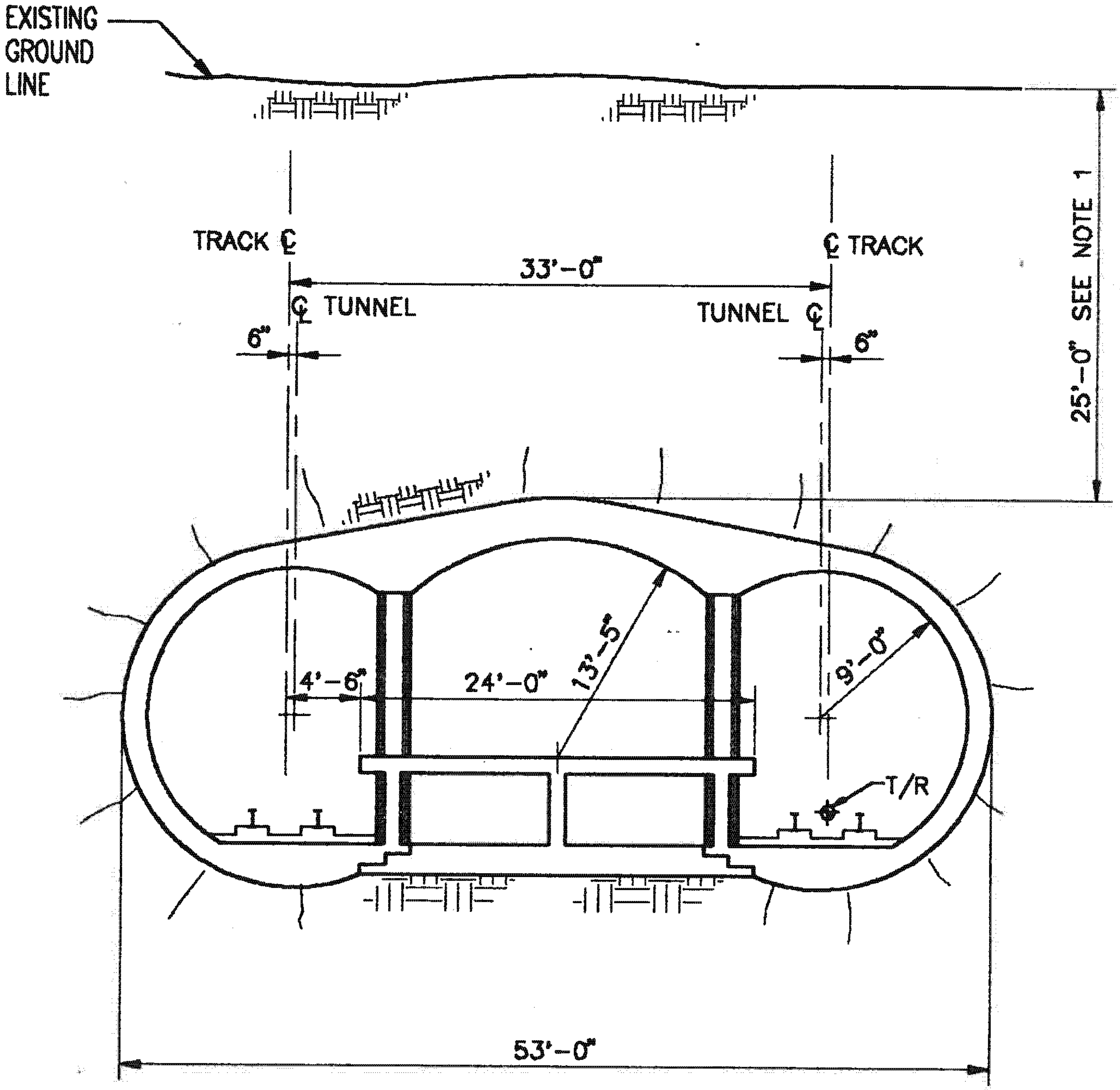
In cut-and-cover excavation, a temporary earth retaining system is first installed from the ground surface. The retaining system might consist of steel sheet piles, soldier piles, and lagging or a



SKETCH 6.1 – CENTER PLATFORM STATION (CUT AND COVER)

NTS

NOTES:
1. DIMENSION VARIES. THE INDICATED, MINIMUM VALUE IS RESERVED FOR EXISTING AND FUTURE UTILITIES.
2. CONSTRUCTION WIDTH WILL EXCEED STRUCTURE WIDTH BY AN AMOUNT CONTINGENT UPON THE SELECTED CONSTRUCTION TECHNIQUE.
3. T/R = TOP OF RAIL.

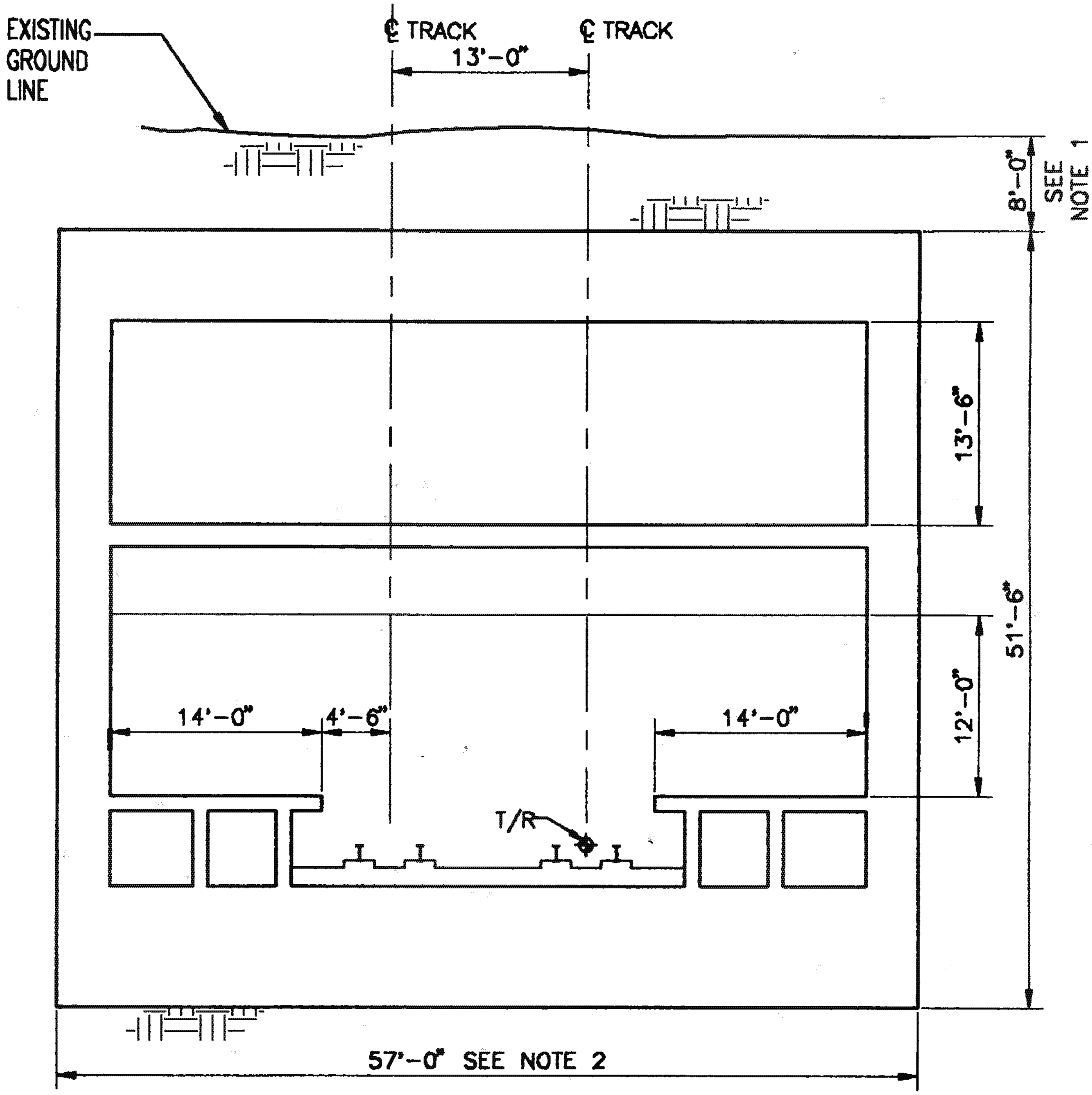


SKETCH 6.2 – CENTER PLATFORM STATION (MINED)

NTS

NOTES: 1. DIMENSION VARIES. THE INDICATED DIMENSION IS THE PREFERRED MINIMUM VALUE FOR CLEAR COVER REQUIREMENTS.

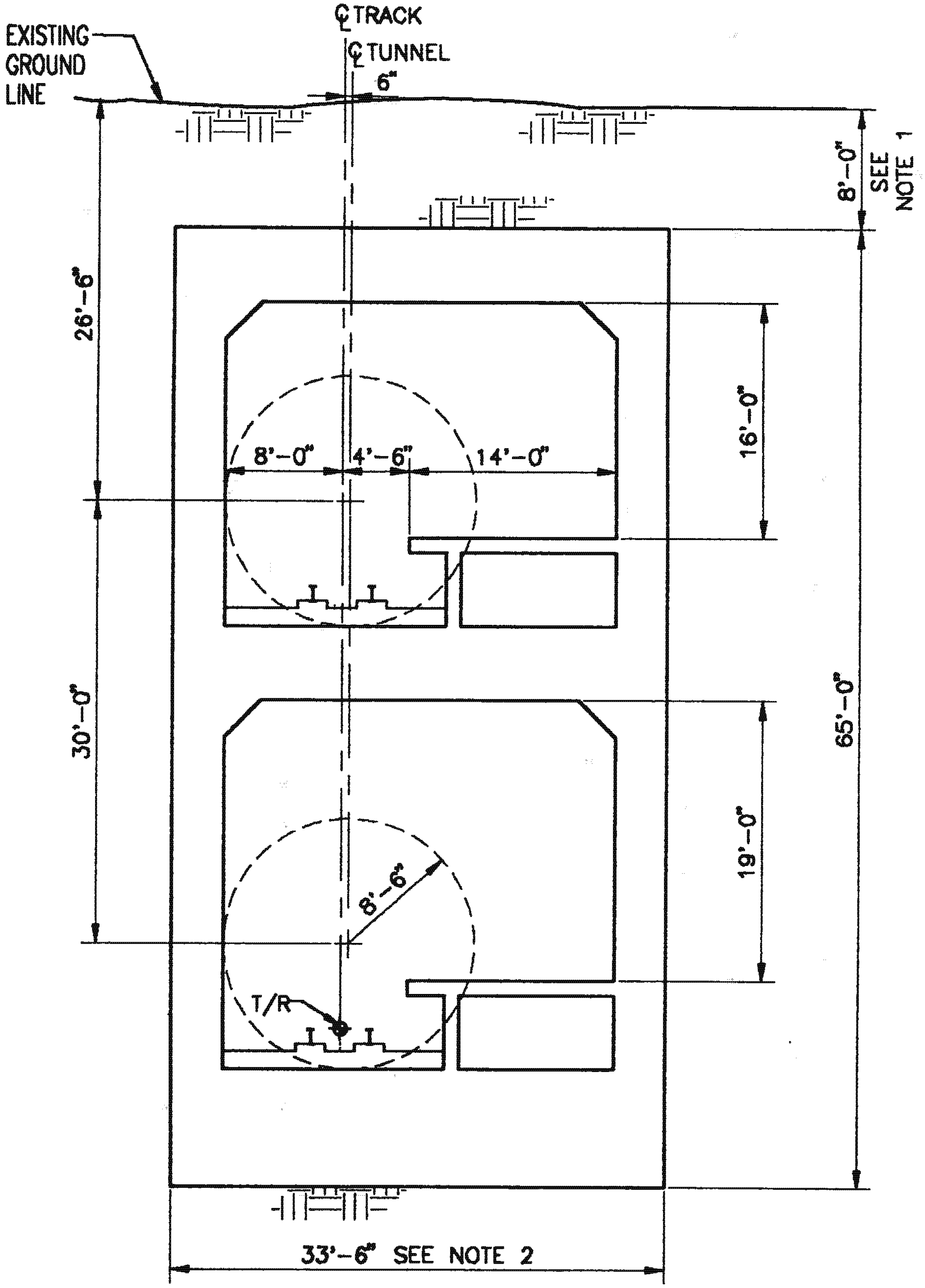
2. T/R = TOP OF RAIL.



SKETCH 6.3 - SIDE PLATFORM STATION (CUT AND COVER)

NTS

NOTES:
1. DIMENSION VARIES. THE INDICATED, MINIMUM VALUE IS RESERVED FOR EXISTING AND FUTURE UTILITIES.
2. CONSTRUCTION WIDTH WILL EXCEED STRUCTURE WIDTH BY AN AMOUNT CONTINGENT UPON THE SELECTED CONSTRUCTION TECHNIQUE.
3. T/R = TOP OF RAIL.



SKETCH 6.4 – STACKED PLATFORM STATION (CUT AND COVER)

NTS

NOTES:
1. DIMENSION VARIES. THE INDICATED, MINIMUM VALUE IS RESERVED FOR EXISTING AND FUTURE UTILITIES.
2. CONSTRUCTION WIDTH WILL EXCEED STRUCTURE WIDTH BY AN AMOUNT DEPENDENT UPON THE SELECTED CONSTRUCTION TECHNIQUE.
3. T/R = TOP OF RAIL.

concrete slurry wall. The choice of system would be dependent upon the depth of excavation, geotechnical conditions, and proximity of surrounding structures.

The earth between the retaining walls is progressively removed and struts placed between the walls to support the excavation. Once the desired elevation is reached, the structure is constructed within the excavation, the excavation backfilled and the temporary retaining system removed or abandoned in place.

Construction is complicated by the presence of a high water table and permeable soils. Such a condition requires the installation and operation of dewatering equipment to allow the construction to progress safely. If the soil consists of soft clays or silts, the lateral loads on the retaining walls will be sizeable, especially for a deep excavation as required for subway construction. The presence of adjacent structures must be carefully considered before beginning construction, and the temporary retaining system should be designed and constructed to minimize damage to these structures.

It is anticipated that any cut-and-cover excavation along the Hotel Street alignment would be accomplished using concrete slurry walls as the earth retaining structure. A slurry wall has benefits in that it can be used to limit deflections of adjacent buildings much more effectively than other systems. The second advantage of the slurry wall is that it can be used to isolate the excavation (a cut-off wall) so that dewatering efforts within the excavation will not draw down the surrounding water table, thereby causing additional settlement of adjacent buildings. Finally, if the slurry walls are properly designed and constructed, they can be utilized as the final structural walls for the station, resulting in substantial savings in both construction time and cost.

Depending on the temporary earth retaining system chosen, the station can be constructed as an independent structure within the excavation or the walls can become a permanent part of the station structure. These alternatives are typically referred to as double-wall or single-wall construction, respectively.

As discussed in the section on line tunnels, there are two major variations of the general construction method utilized for cut-and-cover construction. These are typically referred to as "bottom-up" and "top-down" construction. Both methods are applicable to the construction of underground subway stations and will be addressed separately.

6.5.2.1 *Bottom-up Construction*

Bottom-up construction is the traditional and most commonly utilized method of cut-and-cover construction. This method requires the installation of struts between the temporary retaining walls in a progressive manner as the excavation proceeds downward. The result is that as the excavation progresses, the contractor has a large open hole within which to work. This large open hole makes it easy for the contractor to complete the excavation, provides excellent construction access and gives him plenty of room to construct the station within the excavation.

The Hotel Street Subway alignment runs through permeable soils, completely below the water table; therefore, it will be necessary to dewater the site ahead of the excavation. Once the lowest excavation elevation is reached, the station base slab is constructed to stabilize the bottom of the retaining walls. In progressive order working back upward, intermediate slabs and finally the roof slab are constructed, allowing removal of all remaining struts. Following the installation of waterproofing materials, the excavation is backfilled and the street surface restored. All further work can take place within the confines of the station shell and be supplied at limited access points.

A tremendous volume of spoil materials will have to be removed from the site during excavation. An equally large amount of concrete, reinforcing steel, and other construction materials will have to enter the site during station construction. The large open hole provided by the bottom-up construction method provides almost unlimited access to the site and easily facilitates these activities. Construction vehicle access can be provided by the installation of a temporary deck over a portion of the excavation to allow partial restoration of vehicular traffic on the street above. This would also allow the maintenance of emergency vehicle access to Hotel Street.

From an engineering standpoint, the greatest problem that occurs with cut-and-cover construction has to do with the surrounding surface settlements generated by the excavation. This problem is most serious with bottom-up construction. As the excavation in traditional bottom-up construction progresses, steel struts are installed and prestressed to support the retaining wall. Unfortunately, irrespective of the magnitude of the prestressing, the struts shorten and the walls deflect inward as the excavation progresses.

The magnitude of the problem can be reduced by using thick slurry walls, close strut spacing and high levels of strut preload. However, the inward wall deflection and subsequent surface settlements will often still be unacceptable. This is particularly true where old masonry buildings are found adjacent to deep excavations, which is exactly the situation presented at the Bethel and Alakea Street stations.

6.5.2.2 *Top-down Construction*

Top-down construction is a specialized form of cut-and-cover excavation that is increasingly being used for the construction of large underground structures such as subway stations. A small modification of the traditional excavation procedure makes the top-down method a much preferred alternative for construction in crowded urban areas. The primary benefit is a minimization of surface disruption.

In top-down construction, the temporary earth retaining walls are installed in the normal fashion. These walls are almost always concrete constructed by the slurry-wall method and are normally intended to act as the permanent structure walls. In suitable geologic environments, the concrete slurry walls can also act as cut-off walls to prevent drawdown of the water table outside of the construction site and related surface settlements during dewatering operations.

Excavation proceeds to the elevation corresponding to the underside of the station roof slab. At this point in the sequence, the roof slab is constructed and connected to the slurry walls. Large access holes are left in the roof slab to allow further excavation to continue.

Once the roof slab is completed and the waterproofing applied, the excavation can be backfilled up to the street level with provisions made for continuing access through the holes left in the roof slab and the street resurfaced and opened to traffic. Excavation for the station proceeds by mining with front-end loaders under the roof slab and disposal of the spoils through the access holes. The process is repeated at each intermediate slab level until finally the base slab level is reached and excavation is completed.

From the owners point of view, the advantages of the top-down construction are readily apparent. The first, of course, is that traffic can be restored quickly. This should be a major consideration for the Hotel Street Subway even though Hotel Street itself is closed to traffic. The stations are located under major intersections and construction will seriously affect cross-street traffic. The second, is that by covering the excavation early, the construction noise, dust and associated disruption are reduced considerably. Thirdly, the contractor is forced to carry out all spoil removal and material supply efforts at one or two points, the access holes. These can be located to minimize impact to the surrounding businesses and residents.

The greatest advantage of top-down construction may be in the protection from ground movements it offers existing buildings surrounding the station site. By constructing the four-to-six-foot-thick concrete roof slab before continuing excavation, the contractor has in fact installed a rigid, nearly incompressible strut between the walls. Similarly, by installing each subsequent slab before proceeding with the excavation, the inward wall deflections and related surface settlements are reduced to the absolute minimum obtainable.

6.5.2.3 *Concerns*

Disadvantages of cut-and-cover station construction are identical to those identified for cut-and-cover tunneling. These include maintaining safety around the excavation, conflicts with buried utilities, difficulty in limiting the settlement of surrounding structures, and long-term disruption of surface activities. With the exception of conflicts with buried utilities, all of these concerns are greatly reduced, if not eliminated, with the adoption of top-down construction.

A major concern in any large excavation planned for a public street is conflict with underground utilities. This problem will exist with the adoption of either bottom-up or top-down construction. While cut-and-cover tunnels are normally located a considerable distance below the street level for operational requirements, the roof of an underground station is generally quite close to the ground surface.

It is normally possible to temporarily support the underground utilities as the tunnel excavation proceeds. However, it may be necessary to physically relocate particularly deep utilities. The utilities under Hotel Street, as currently known, have been reviewed and no serious conflicts with the stations have been identified. This issue will be further investigated during the preliminary engineering phase of the contract.

6.5.3 Mined-Cavern Excavations

Several modern subway systems have passenger stations constructed with mined-cavern excavation techniques. The construction of these stations is often complex; however, the benefit associated with minimized surface disruptions generally exceed the negative aspects associated with mining underground station caverns.

Due to the irregular shape of underground passenger stations, the cavern excavation is usually performed by "hand-mining" techniques. These techniques include excavation by mechanical equipment such as road headers, hand-held equipment, or drill-and-blast methods. The site-specific geology is instrumental in determining the selected excavation method. Ultimately, large volumes of earth are removed from below grade, either through a tunnel portal or through a vertical access shaft. The structural stability of the resultant void or cavern is usually ensured by the installation of either temporary or permanent lining systems. There are a multitude of lining systems that effectively provide the required stability, each with particular characteristics suitable for specific environments.

The geological conditions along the Hotel Street Subway alignment are not favorable for the construction of mined cavern subway stations. The geology is composed of soft ground and pervious corals with voids, well below the water table. The groundwater would have to be controlled with compressed air or by dewatering with deep wells. The following discussions will be limited to those lining systems and associated construction methods that may potentially be feasible for the Hotel Street Subway environment.

6.5.3.1 *New Austrian Tunneling Method (NATM)*

One technique that is used in modern cavern construction is the New Austrian Tunneling Method (NATM), which often uses drill-and-blast methods to excavate the opening and shotcrete to promptly support the newly excavated opening. NATM advance rates are slow because the shotcrete is applied after each short advance effort, but the prompt support by the shotcrete often reduces the surface settlement above the cavern.

The presence of a high water table will greatly complicate the situation. In soft ground, the excavation would have to be supported immediately, and for a large mined cavern, shotcrete is the preferred support material. Shotcrete will not adhere to wet, soft ground, and normally compressed air is used to "dry out" the ground or deep wells to remove the groundwater would be necessary. However, the compressed air option is not desirable because of the pervious nature of the coral. Voids in the coral, filled with water but connected to the surface, could provide routes for the compressed air to escape. Any rapid loss of air pressure underground could be catastrophic.

The remaining option, which is to dewater the area using deep wells, is safer than the use of compressed air in the corals that exist along Hotel Street. However, dewatering would require a significant drawdown of the water table with a correspondingly large radius of drawdown around the subway station. This widespread lowering of the water table by conventional dewatering is considered a threat to surrounding structures because of the possibility of increased surface settlements and building damage.

6.5.3.2 *Jacked Pipe Arch*

An alternate solution to soft-ground mined-cavern construction is to jack or drive a "pipe arch" of medium-sized steel or concrete pipes (perhaps 3 to 5 feet in diameter) along the roof. After this pipe arch is safely in place, excavation is made carefully under the protection of the pipe arch which is kept supported at all times.

Again, the construction effort is tedious and complicated by high ground water elevations. Additionally, the existence of corals at the proposed station locations would seriously curtail the ability to jack the pipe sections which form the initial arched roof.

6.5.3.3 *Concerns*

Construction of mined caverns below the water table is possible in favorable geological conditions. If the geologic material is such that the presence of groundwater poses no hazard, the work can proceed. In some hard rocks free of joints, fissures, faults, and weathered zones, the water presents little difficulty and construction can proceed safely and economically. Pumps must be provided to remove the excess water.

If the geological material is jointed, faulted, and weathered, the presence of the water is a potential threat. If the water loosens the rock blocks or causes the weathered materials to erode, the entire rock mass may unravel and a rapid, unpredictable failure may occur.

If the geological material is soft ground, the presence of the water is an active threat. The water can loosen the soft ground materials and carry them away, with a consequent unravelling of the ground and imminent failure. Excavation in soft ground below the water table must be supported immediately. For large mined caverns of irregular shape, support is usually provided by shotcrete. For shotcrete to adhere properly, the ground must be stable and reasonably dry.

One solution to the problem of shotcrete placement on soft ground below the water table is the use of compressed air. The compressed air drives the groundwater away from the exposed face and, thus, "dries out" the soft ground long enough for the successful placement of the shotcrete. Compressed air does introduce difficulties such as health hazards, potential blow-outs resulting in rapid decompression, and construction complexities with associated cost implications.

A second solution to the problem of shotcrete placement on soft ground below the water table is to lower the water table until the work is "in the dry." This solution would mean conventional dewatering with deep wells for some hundreds of feet along the length of the proposed subway station. The resulting surface settlement due to this dewatering would extend for several thousands of feet in all directions from the dewatering, and requires careful evaluation before use.

6.6 Conclusion

The Hotel Street Subway, as currently envisioned, contains three underground stations identified as Hotel/Bethel, Hotel/Alakea, and Civic Center Station. Internally, the passenger stations are generally configured with platform orientations described as center, side, or stacked. Selection of a station configuration is based on an array of parameters including functional/spatial design considerations, expandability, contextual considerations, right-of-way issues, and joint development potential.

The Hotel Street Subway, as currently envisioned, contains three underground stations identified as Hotel/Bethel, Hotel/Alakea, and Civic Center Stations. Internally, passenger stations are generally configured with platform orientations described as center, side or stacked. Selection of a station configuration is based on an array of parameters including geological constraints, functional/spatial design considerations, expandability, contextual considerations, right-of-way issues, and joint development potential.

The geotechnical boring logs taken along Hotel Street indicate that the underlying coral is not continuous but very irregular with interbedded layers of soft silt and clay found in random, unpredictable locations. These soft materials increase the potential of building damage during excavation of the stations. For this reason the narrower stacked station configuration was chosen, thereby maximizing the clearance between subway construction and adjacent buildings, reducing the risk of settlement damage and providing space to underpin buildings if necessary. These constraints are not an issue for the Civic Center Station, and therefore a traditional center platform station was proposed. The center platform configuration is deemed superior to a stacked platform configuration, especially with regard to passenger circulation.

As with the line or running tunnels, the passenger stations are typically constructed using either mined or cut-and-cover techniques. Two mined-cavern excavation methods have been addressed as a part of this feasibility study. They are the New Austrian Tunneling Method (NATM) and a Jacked Pipe Arch method. Both methods may be feasible but did not appear favorable in light of the existing subsurface conditions. NATM is flawed by the relatively high water table and the risks of using compressed air in the voided coral. The jacked pipe arch scheme is complicated by the high water table and the existence of corals that may curtail the ability to jack the pipe sections. Therefore, a traditional cut-and-cover method was identified as the probable solution.

The order of magnitude cost estimate was not performed at a level of refinement to distinguish between a top-down or a bottom-up construction sequence. However, the costs were estimated assuming a concrete slurry wall as the earth retaining structure. A slurry wall has benefits in that it can be used to limit deflections of adjacent buildings much more effectively than other systems. Additionally, a slurry wall can be used as cut-off wall to isolate the station excavation so that dewatering efforts within the excavation will not draw down the surrounding water table, thereby causing additional settlements of adjacent buildings.

7. SUBWAY OPTIONS

7.1 Introduction

Based on the many considerations discussed in Section 6, three alternative stacked-platform station configurations were prepared for the Hotel/Bethel and Hotel/Alakea stations. Only one basic configuration was explored for the Civic Center Station because of its relative lack of constraints. The alternatives and their merits are discussed below. Sketches 7.1 — 7.6 for these options are presented at the end of Section 7.

7.2 Hotel/Bethel Station Configuration Options

7.2.1 Station Configuration Option "A" (Sketch 7.1)

Under Option "A" for the Hotel/Bethel Station, the stacked guideway tunnels would be located on the mauka side of Hotel Street, with the station platforms on the makai side. The tunnels and station platforms fit within the existing 50-foot-wide right-of-way.

Two station entrances located at opposite ends of the station and approximately 800 feet apart would be provided. The Ewa entrance would be located just Koko Head of Maunakea Street on the surface parking lot currently occupied by a taxi company. Two escalators and a stair provide access to the upper station platform level. Within the Hotel Street right-of-way, the upper platform would be connected to the lower platform by two single escalator/stair combinations.

This station entrance would serve the Chinatown Special District and the many shops and offices located along North Hotel Street; Maunakea Street, Smith Street, and Nuuanu Avenue.

The Koko Head station entrance would be located on private property in the Empire Building on the Koko Head side of Bethel Street. The development of this block, known as the "Campbell Project," is proposed. Two escalators, an elevator, and a stairway would provide access to each platform level.

This station would serve the nearby Liberty House department store and the many shops and offices located along South Hotel Street, Bethel Street, Nuuanu Avenue, and the Fort Street pedestrian mall.

7.2.2 Station Configuration Option "B" (Sketch 7.2)

Under Option "B" for the Hotel/Bethel Station, the stacked guideway tunnels would be located on the makai side of Hotel Street with the station platforms on the mauka side. The tunnels and station platforms fit within the existing 50-foot-wide right-of-way.

Only one station entrance, located just Koko Head of Bethel Street, on private property now occupied by the Marine Finance Building is provided. Two escalators, a stairway, and an elevator provide access to the upper station platform level. Beneath Bethel Street and the Chinatown Gateway Park, a second bank of escalators and stairs would serve the lower platform. The elevator would serve both platform levels.

This station entrance would serve the nearby Liberty House department store and the many shops and offices located along North Hotel Street, Bethel Street, the Fort Street pedestrian mall, Nuuanu Avenue, and Smith Street.

7.2.3 Station Configuration Option "C" (Sketch 7.3)

Under Option "C" for the Hotel/Bethel Station, the stacked guideway tunnels would be located on the mauka side of Hotel Street as in Option "A," with the platforms on the makai side, stretching between Nuuanu Avenue and Bethel Street. The tunnels and station platforms fit within the existing 50-foot-wide right-of-way.

Two station entrances, located at opposite ends of the station approximately 650 feet apart, are provided. The Ewa entrance would be located within the Hotel Street right-of-way approximately 80 feet Ewa of Nuuanu Avenue. Two escalators and a stairway would provide access to the upper station platform level within the station, near the Nuuanu Avenue end; an escalator and stairway would serve the lower platform level. This station entrance would serve the Chinatown Historic District and the many shops and offices located along North and South Hotel streets, Nuuanu Avenue, Smith Street, and Bethel Street.

The Koko Head station entrance would be located approximately 100 feet makai of Hotel Street in the Fort Street pedestrian mall. This entrance would provide a two-level underground pedestrian concourse under Hotel Street connecting both this station and the Hotel/Alakea station. Two escalators, a stairway, and an elevator would provide access to both concourses and platform levels.

This station would serve the nearby Liberty House department store and the many shops and offices located along South Hotel Street, Bishop Street and the Fort Street Mall.

7.3 Hotel/Alakea Station Configuration Options

7.3.1 Station Configuration Option "A" (Sketch 7.4)

Option "A" for the Hotel/Alakea Station corresponds with Option "A" for the Hotel/Bethel station. The relative location of the guideway tunnels and platforms are consistent for both.

Two separate station entrances located at opposite ends of the station, approximately 700 feet apart, are provided. The Ewa entrance would be located in the Hotel Street right-of-way approximately 60 feet Koko Head of the Fort Street pedestrian mall on the makai side. A standard two escalator/stairway bank would provide access to the upper platform level. The lower platform level would be accessed by two single escalator/stair banks.

This station entrance would serve the many shops and offices located along South Hotel Street, the Fort Street Mall, Union Mall, and Bishop Street, including the Pan-Pacific Plaza Tower building now under construction.

The second entrance would be located approximately 70 feet Koko Head of Alakea Street, on the makai side of Hotel Street. A standard two escalator/stairway/elevator bank would be provided. A portion of the entrance would be located on private property in the plaza area for the Alii Place development, currently under construction. A second two-escalator/stairway bank and a second elevator would connect the upper and lower platform levels. A below-grade easement would be required under the Pau'ahi Tower plaza area on Hotel Street near Alakea Street to accommodate this vertical circulation element.

This station would serve the two large new office buildings now under construction (1100 Alakea and Alii Place), the District Courts Building and Pau'ahi Tower as well as the State Capitol and Iolani Palace areas two blocks Koko Head.

7.3.2 Station Configuration Option "B" (Sketch 7.5)

Option "B" for the Hotel/Alakea Station corresponds with Option "B" for the Hotel/Bethel station. Two entrances located at opposite ends of the station, approximately 500 feet apart, are provided. The Ewa or Fort Street Mall entrance would be located on private property currently occupied by the two 3-story buildings housing McDonald's, Taco Bell, and Jack-in-The-Box restaurants on the mauka side of Hotel Street. A standard two escalator/stairway/elevator bank would provide access to the upper platform level and a two escalator/stair bank would connect the two platform levels. The elevator would serve both levels.

This station entrance would serve the many shops and offices located along South Hotel Street, the Fort Street Mall, Union Mall, and Bishop Street.

The second station entrance would be located approximately 120 feet Ewa of Alakea Street in the Hotel Street right-of-way, mauka side. A standard two escalator/stairway/elevator bank would provide access to the upper platform level and a single escalator/stair bank would connect the two platform levels.

This station entrance would serve the two large new office buildings now under construction (1100 Alakea and Alii Place), the District Courts Building, and Pauahi Tower as well as the State Capitol and Iolani Palace areas two-and-a-half blocks Koko Head.

The Ewa vertical circulation structures will require easements on the mauka side of Hotel Street under the Taco Bell and Jack-in-The-Box buildings between the Fort Street and Union Malls. A portion of one of the vertical circulation elements would also encroach under the Union Street Mall.

7.3.3 Station Configuration Option "C" (Sketch 7.3)

Option "C" for the Hotel/Alakea Station corresponds with Option "C" for the Hotel/Bethel Station.

Two entrances located at opposite ends of the station approximately 500 feet apart are provided. The Ewa or Fort Street Mall entrance would be the same as described, with the Koko Head entrance to the Hotel/Bethel Station, as was described under Option "C" for that station.

The second station entrance would be located approximately 120 feet Ewa of Alakea Street in the Hotel Street right-of-way, makai side. A two escalator/stairway bank would provide access to the upper platform level and a single escalator/stairway bank would access the lower platform level.

This station entrance would serve the two large new office buildings now under construction (1100 Alakea and Alii Place), the District Courts Building, and Pauahi Tower as well as the State Capitol and Iolani Palace areas.

7.4 Civic Center Station Configuration

7.4.1 Station Configuration Option "A" (Sketch 7.6)

Option "A" for the Civic Center Station is compatible with all of the previously discussed Hotel Street station options.

The Civic Center Station is configured as a center-platform station located partially under lawn and landscaped areas makai of the Municipal Building, and partially under the intersection of South King Street, South Street, and Kapiolani Boulevard. Mezzanine levels are provided at both ends of the station, permitting flexibility in locating station entrances.

The Ewa or Civic Center Station entrance would be located approximately 130 feet Ewa of South King Street and 100 feet makai of the Municipal Building. This station entrance would contain a two escalator/stairway/elevator bank accessing the mezzanine level. A second bank of escalators, stairs, and an elevator would serve the station platform one level below the mezzanine.

This station entrance would serve the Honolulu Civic Center area, the nearby State Capitol and office buildings.

The Koko Head entrance would be located at the southwest corner of the intersection of South King Street, South Street, and Kapiolani Boulevard on private property directly mauka of the Kawaiahao Plaza building. This station entrance would contain a two escalator/stairway/elevator bank accessing the Koko Head mezzanine level. A second bank of escalators, stairway, and elevator would access the station platform level.

This station entrance would serve the many offices and businesses located along the Koko Head side of South King Street, South Street, and the Ewa end of Kapiolani Boulevard.

7.5 Assessment of Alternate Station Functional Configurations

7.5.1 Hotel/Bethel Station

Although the Koko Head station entrance for Option "A" is on private lands, it can be incorporated into the proposed redevelopment of that property. Functionally, the entrance and vertical circulation elements work well and provide direct access to both platform levels. The Ewa entrance, located at Maunakea Street also requires a property take but will provide good access to Chinatown. In addition, as this entrance would not be within the Hotel Street right-of-way, weather-proofed escalators would not be required and the maintenance and security issues inherent in Option "A" would not exist. The two in-line vertical circulation elements and the location of the Ewa entrance will require more cut and cover within Hotel Street than Option "B."

Option "B" requires the least cut and cover of the three alternatives because there is only one station entrance. As a result, Option "B" does not serve Chinatown as well as Option "A." This configuration provides a good functional arrangement of vertical circulation and platform access. However, extensive demolition and renovation of the recently completed Chinatown Gateway Park would be required as well as the acquisition of private property to provide the station entrance.

Option "C," while providing a station entrance on the Fort Street Mall, would require more cut and cover than the other two alternatives. The Ewa entrance, located within the Hotel Street right-of-way, would in all likelihood have to be open to minimize the visual obstruction of adjacent storefronts. An open configuration will require weather-proofed escalators and generally presents on-going maintenance and security problems.

7.5.2 Hotel/Alakea Station

Option "A," as illustrated in Sketch 7.4, would in all likelihood require that both entrances be open to avoid the visual obstruction of adjacent buildings and shops. The open entrances would result in similar maintenance and security issues as discussed previously for the Hotel/Bethel Station. However, the Ewa entrances could potentially be incorporated into the Executive Centre building, thereby eliminating part of the problem.

The station as configured provides good access to the Fort Street Mall and major developments near the Koko Head entrance. Minor property takes would be required for that entrance.

Option "B" would require less cut and cover than the other two alternatives but a significant property take, involving three major fast-food chains, would be required to provide the Ewa entrance. This option also provides good access to the Fort Street Mall and minor developments near the Koko Head entrance. That entrance would also be open and therefore present the same maintenance and security issues as discussed previously.

Option "C" for this station presents the same issues as discussed under the "C" Option for Hotel/Bethel.

7.5.3 Civic Center Station

As only one configuration has been prepared for the Civic Center Station, no alternative assessment is required.

7.6 Construction

7.6.1 Constructability

Construction of the Hotel Street Subway project is envisioned to utilize both cut-and-cover and mined-tunneling techniques. Ideally cut-and-cover construction would be limited to subway stations, station entrances, and short lengths of the running tunnels adjacent to the tunnel portals. Mined tunnels would be utilized for the remaining portions of the subway system, which principally consists of the running tunnels.

As discussed in Sections 4 and 5, the geology along the Hotel Street alignment is quite complex and, considered in conjunction with the existing features, will result in an environment that greatly complicates any selected construction method. In terms of the three subway options "A," "B," and "C," there are only minimal variations relevant to constructability. The principal differences are related to the physical location of the stations, the limits or actual length of cut-and-cover construction, and the length and location of individual station entrances.

The location of the passenger stations is essentially the same for all three schemes. Differences in building protection, underpinning, and construction duration would be minimal. Options "A" and "C" have nearly twice the length of cut-and-cover construction as compared to option "B." This variation is primarily due to the entrance configuration. Constructability is likely to be influenced by the degree of surface disruption and efforts utilized by the contractor to minimize the impacts of open-cut construction. The constructability of options "A" and "B" is diminished by the short lengths (approximately 900 feet) of mined tunnel construction that are designated between the station boxes. For this reason option "C" possesses an advantage above the other schemes in terms of constructability.

7.6.2 Construction Time

The construction duration of the Hotel Street Project is estimated to be approximately three years. There is no meaningful variation in construction duration between the three subway options.

7.6.3 Construction Impact on Surroundings

Construction impacts on the surrounding environment by the various options will be differentiated primarily by the extent of proposed cut-and-cover construction. Consequently, Option "B," which is depicted with the least amount of cut-and-cover construction would possess an advantage over the remaining subway schemes.

7.7 Environmental Impacts

7.7.1 Introduction

This section presents a summary of some of the potential environmental impacts of the three options under consideration for the Hotel Street Subway. The range of impacts includes both construction and operational impacts that will have to be dealt with by the Hotel Street Subway contractor under guidance of the City and its GEC. Additional details for some of the impacts can be found in the *Alternatives Analysis and Draft Environmental Impact Statement* (UMTA/City and County of Honolulu, March 1990).

A Final Environmental Impact Statement (Final EIS) will be prepared at the end of Preliminary Engineering. The Final EIS will address the comments received on the Draft EIS and will contain the results of additional analysis conducted in sections of the alignment that might have changed since publication of the Draft EIS.

The primary environmental impacts discussed are traffic, business disruption, noise and vibration, visual, air quality, historic, and disposal of construction wastes. All potential environmental impacts are similar for all the Hotel Street options, unless specifically noted in the text.

7.7.2 Short-Term Impacts During Construction

Traffic

Traffic impacts during construction of the Hotel Street tunnel are a serious concern. Street sections at stations and portal locations, including some cross streets at intersections, would be closed for a period of months while cut-and-cover construction takes place. Hotel Street is currently closed to general traffic; however, bus traffic would be rerouted as part of construction under all options. General traffic on the affected cross streets also would be diverted to adjacent streets. For example, general traffic in the vicinity of the South King Street/South Street/Kapiolani Boulevard intersection would require rerouting during the construction of the Civic Center Station. Because of the diverted traffic, additional congestion and travel delays would occur. The closure of streets, however, would be kept to a minimum. As soon as excavation proceeds to sufficient depths, traffic decks would be built and streets reopened. To minimize impacts, cross street closing would be alternated; not all streets would be closed at the same time.

In areas of the alignment where the subway would be bored rather than cut and cover, the disruption to local traffic, circulation, and access would be much less severe. While it is likely that through traffic would be diverted in the vicinity because of the cut-and-cover station and portal construction, access to businesses would be maintained. Impacts on businesses, especially small businesses, would be much less severe, as compared to the areas adjacent to the cut-and-cover construction.

Access for pedestrians would be maintained to all properties along the alignment throughout the construction period. Access, however, would become less convenient during construction and temporary sidewalks could be required.

A detailed Maintenance-of-Traffic-Plan for the tunnel would be prepared for the construction period with a set of transit and general rerouting schemes for each tunnel construction phase as appropriate. The rerouting of transit and general traffic would cause varying degrees of congestion depending on the rerouting schemes chosen. The plan would address ways to maintain traffic, bus service, and pedestrian activity while allowing for the delineation of a construction area. Bus stops currently within the construction area would be relocated during construction. The locations of the temporary/permanent bus stops would depend on the rerouting schemes selected.

Construction traffic routes would be specifically identified in the plan. The routes would be selected to minimize traffic and other impacts on nearby residences and businesses. For example, truck traffic could be limited to off-peak hours and to streets not utilized by bus rerouting. The draft of the Maintenance-of-Traffic Plan would be prepared by the Hotel Street Subway contractor. The plan would be reviewed by the City and its GEC and revised based upon the City's comments. The City would have final approval for the contractors plan, but it would be the responsibility of the contractor to execute the plan. The City would monitor compliance.

Included as part of the plan, would be an aggressive public information program to alert motorists and commuters about delays during tunnel construction to reduce initial confusion. People would be given information and time needed to adjust their personal travel habits. During special events, construction activity could be modified, if needed to minimize the effect on the event.

In addition to the disruption of local traffic, congestion in the area of construction would increase due to the impact of construction vehicles. Vehicle traffic into and out of the construction area each day would be substantial. Construction traffic includes a wide variety of vehicles moving to the construction sites, ranging from additional cars and small trucks to much larger trucks used for the delivery of major pieces of equipment and for hauling away construction spoils. The heaviest area of construction traffic would be in the vicinity of the stations and portal construction area. A large number of trips would be made from these areas with excavated materials. Construction traffic would be included in the Maintenance-of-Traffic Plan. The routes would be selected to minimize traffic and other impacts on nearby residents and businesses. For example, truck traffic could be limited to off-peak hours and to streets not utilized by bus rerouting.

Business Disruption

During construction there would be some business disruption. Disruption would be the greatest in the areas of cut-and-cover construction at the station and portal locations. Temporary access would be maintained, especially where businesses do not have alternative street access. In those areas of the alignment that would be bored tunnel construction, business access disruption would be less because the street would not be excavated. Businesses in the area, however, would still experience some disruption due to alternative traffic patterns and delays.

Noise and Vibration

Construction noise would be an adverse impact on nearby residences, office buildings, and other sensitive uses. Noise would be the highest during the street-level construction. For the cut-and-cover approach in the station location, construction machinery would typically operate in direct line of sight with buildings adjacent to the alignment until the excavation was deep enough that the excavation walls would act as noise barriers. For the portions of the tunnel that would be bored, noise generated by the tunnel boring machine would be effectively muffled by the ground between the tunnel and the surface.

There also could be some increase in noise on streets in the vicinity as a result of rerouted traffic. The contractor would be required to comply with the Community Noise Control requirements of the State of Hawaii.

Vibration impacts also could occur along the bored tunnel section as the boring machine moves along. Ground-borne vibration could cause problems in existing buildings such as cracks, loosening of paint, and falling plaster. Specific structures and buildings adjacent to construction operations would require monitoring during construction. A preventive program would be established to minimize the impacts of vibration during construction.

Visual

Construction would add some visual clutter to the project area; however, it would be temporary in nature. It also should be noted that a majority of the construction work would occur below grade along Hotel Street, except in the areas of cut and cover at station and portal locations.

Air Quality

Direct air quality impacts would be caused by exhaust emissions from heavy-duty construction trucks and construction equipment replacing pavement and excavation that usually generate substantial dust. Dust blowing from uncovered trucks and soils raised by construction vehicle frames and tires could be deposited on adjacent streets.

Increases in traffic congestion near the construction site also would indirectly affect air quality. Normal traffic patterns would be interrupted and traffic speeds could be reduced if there are traffic lane closures. Slower speeds would increase vehicle emissions.

During construction, the impact on air quality could be reduced if slow-moving trucks were kept at a minimum during peak hours and the contractor was required to cover all uncovered trucks carrying soils from the tunnel excavation.

Historical/Archaeological

The Hotel Street Subway passes through the Chinatown and Hawaii Capital Special Districts. Along the Hotel Street Subway alignment in the Hawaii Capital Special District, are the State Capitol, Iolani Barracks, Iolani Palace Complex, Old Archives Building, Hawaii State Library, Honolulu Hale, and the Mission Memorial Building and Annex. Along Hotel Street within the Chinatown Special District are the Hotel Street Elements; outside the District is the J. Campbell Building, and the Portland Building. Further Koko Head on Kapiolani Boulevard, adjacent to the alignment, is the Advertiser Building. It is assumed that all buildings, including historic buildings, would not be affected. Mitigation for the project, as discussed under Noise and Vibration, includes measures to ensure that the integrity of all structures on or adjacent to the alignment remain. Also, design measures would be incorporated to minimize impacts to historic buildings caused by their proximity to amenities such as station entrances and vents.

Based on discussions between the City and the State Historic Preservation Officer (SHPO), mitigating measures such as photo documentation could be required as part of a Memorandum of Agreement (MOA) should the Nuuanu Stream Bridge (within the Chinatown Special District) be demolished.

A tunnel requires extensive excavation. It is therefore anticipated that some sites of archaeological value will be uncovered. Additional studies, including a testing and monitoring program, would be required later in the design phase. The monitoring plan should include a burial disinterment program.

Parklands

Four parks have been identified along the Hotel Street alignment: Union Mall Park, Fort Street Mall, Chinatown Gateway Plaza, and the Iolani Palace State Monument. It is not anticipated that Option "A" would require the permanent taking of any parkland; therefore, no 4(f) impacts are anticipated. Option "B," however, would require a temporary construction easement from Gateway Plaza for construction of a station at Bethel and Hotel streets. The station entrance would be on the mauka/Koko Head corner; therefore, the easement from Gateway Plaza would be short term only. Option "B" also would have a station entrance onto the Fort Street Mall, although there would not be any taking of parkland from the Fort Street Mall. Option "C" would require permanent right-of-way to construct a station in the Fort Street Mall makai of Hotel Street, near the entrance to the J. Campbell Building. None of the parks would be used as a construction staging area.

7.7.3 Long-Term Impacts

Traffic

After construction has been completed, previous traffic patterns would resume with the exception of the bus traffic rerouted from Hotel Street to other nearby streets.

Business Displacement

Generally, the Hotel Street displacements would be greatest in the portal areas. The Ewa portal would displace approximately five businesses; the Koko Head portal would displace approximately 21 businesses. With the construction of Option "A," there would be an additional eight storefront businesses displaced plus 17 businesses displaced on the second and third floors of the Empire Building. For Option "B" there would be five storefront businesses plus 35 businesses on the second, third, and fourth floors of the 1109 Bethel building that would be displaced in addition to the portal-related displacements. There would be no additional business displacements with Option "C."

Noise and Vibration

Although adverse airborne noise impacts would be eliminated, there is the potential for groundborne noise and vibration impacts on buildings along the alignment. The extent of this impact would be dependent on the selected technology. The area of potential impact would be greater for conventional rail technology than for magnetic levitation systems. In the first technology, the noise of trains passing by could be audible in small buildings along the alignment but would not be objectionable. For the latter technology, vibration levels are expected to be unnoticeable.

Visual

After construction, the Hotel Street Subway would not have any significant visual impacts except in the areas of the station and portal entrances. The design of the station entrances would be integrated into the context of the surrounding areas and subject to design review as part of the Chinatown and Capitol Historic districts. Vents also would have to be integrated into the streetscape.

Historic/Archaeological

Design of the station entrances and vents would be contextual to the architecture and character of the Chinatown and Hawaii Capital Special Districts minimizing impacts caused by the proximity of the transit project. Such provisions would be included in the Memorandum of Agreement (MOA).

Once construction was completed, there would not be any additional potential impacts to archaeological resources.

Parklands

As discussed under construction impacts, Option "C" would require permanent right-of-way to construct a station in the Fort Street Mall makai of Hotel Street. The 4(f) process would have to be completed for the taking of any parkland prior to any project approval.

Once construction of the alignment was complete, there would not be any potential impacts to any other parkland resources as a result of the transit project.

7.8 Construction Cost Estimate

7.8.1 Introduction

An order of magnitude cost estimate has been prepared for the three Hotel Street Subway configurations defined as Options "A," "B," and "C." From an estimating perspective, the major distinctions are:

- Option "A": Stacked-platform stations with guideways along the mauka side of Hotel Street
- Option "B": Stacked-platform stations with guideways along the makai side of Hotel Street
- Option "C": Combined stacked-platform stations with guideways along the mauka side of Hotel Street.

7.8.2 Definition Documents:

The following documents were used in the preparation of these estimates:

- Sketches 7.1 through 7.6
- *Draft Geotechnical Engineering Exploration* (June 1991)
- *Draft Hotel Street Subway Reference Drawings* (June 1991).

7.8.3 Pricing

Pricing of all construction elements includes labor, burden, construction equipment usage, material, permanent equipment, contractors' overhead and profit, and design by the turnkey design/construct contractor. Current quotes were obtained for selected materials.

7.8.4 Scope

The estimate includes all costs for the proposed Hotel Street procurement contract and other costs to the City so that a valid comparison may be reached. The other costs to the City include station finishes, the Hotel Street Mall, landscaping, right-of-way, engineering and management. Costs not included are those associated with System Vendor procurements.

This estimate specifically includes the following items:

- Demolition: Includes demolition of buildings and removal and reconstruction of existing canopies, awnings, fountains, etc.

- Utility Relocation: Complete cost of all public utilities has been included. Cost was determined by review of utility drawings for Kuhio Street in Waikiki and factoring this by judgment to Hotel Street.

- Street Modifications: Included are street, curb, and sidewalk demolition and reconstruction.

- Underpinning: Cost of underpinning includes preconstruction grouting as well as conventional underpinning with driven piles and/or jack piles. Also included is post construction repairs as required. Cost was determined by building-site inspections with assumed foundation conditions. Foundation conditions for selected structures were determined by consulting building owners and gathering other available information.

- Subway: Cost of subway includes excavation, preexcavation stabilization where required, and structure. Tunneling generally assumes use of an earth pressure balance (EPB) tunnel boring machine. Cut-and-cover construction generally assumes slurry-wall construction utilizing the "top down" method.

- Stations: Cost of stations includes excavation, preexcavation stabilization where required, structure, and all station finish work, including escalators and elevators. All stations are constructed using cut-and-cover construction generally assuming slurry-wall construction utilizing the "top down" method.

- Hotel Street Mall: Included are new concrete subbase, hardscape, planters, furniture, and associated electrical fixtures.

- Landscaping: Included are waterfalls, landscaping along Hotel Street and landscaping inside the subway stations.

- Engineering and Management: Included are engineering supervision and construction management by the General Engineering Consultant (GEC) and engineering and administration by the City. Excluded are preliminary engineering, and preoperating expenses by the City. Preoperating expenses refer to the cost of maintaining and operating a facility during the period of time between completion of construction and initiation of revenue service.

- Contingency: An allowance to cover design development and unforseen conditions/uncertainties (i.e., geotechnical issues, etc.) that are recognized in the very approximate estimating methods used at this stage of the project.

7.8.5 Cost Exclusions

1. Systemwide elements including vehicles, trucks, signals, etc.
2. Preliminary engineering
3. Owner (City) cost for financing and preoperating expenses
4. Operating costs
5. Project Reserve for change orders and scope enhancements.

7.8.6 Escalation

This estimate is considered to be in June 1991 dollars. No escalation is included.

7.8.7 Cost Breakdown

A summary of the costs for each option on the Hotel Street Subway are on the following table.

ICF KAISER ENGINEERS, INC.
HOTEL STREET SUBWAY
JOB NO. 91184 (REV 0)

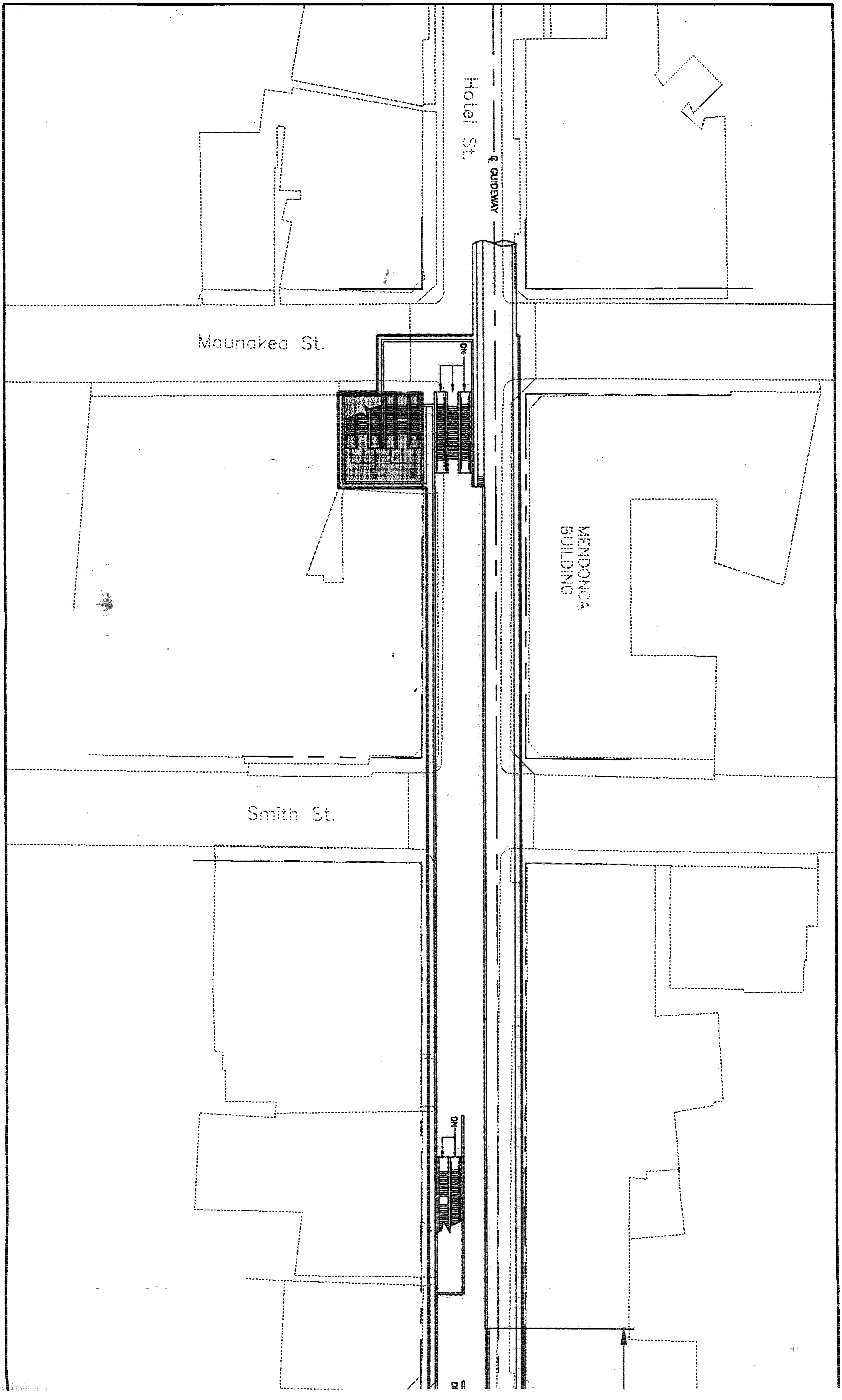
DATE: 05–Jul–91

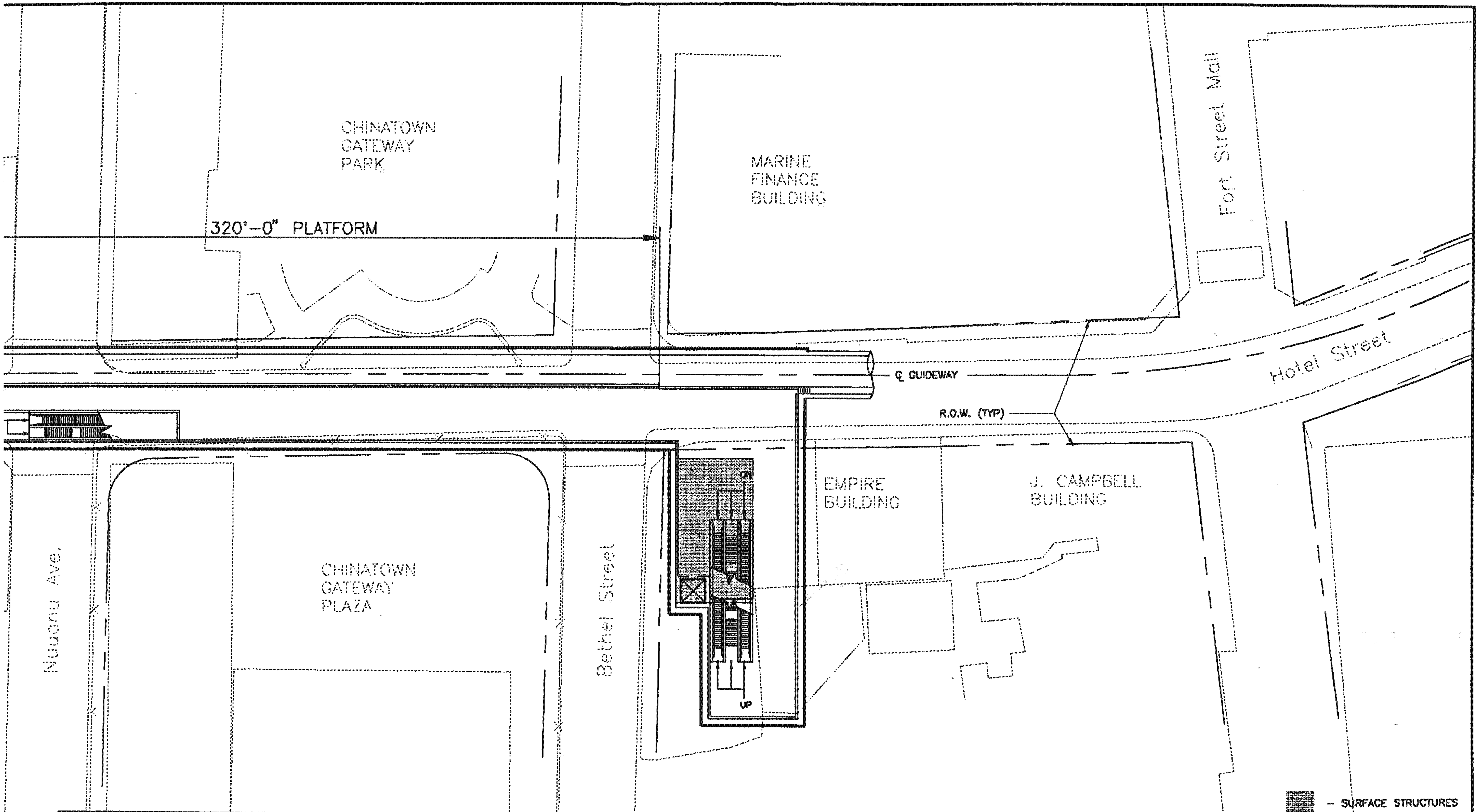
COMPARISON OF ALTERNATIVES: HOTEL STREET SUBWAY

(Cost Unit or Multiplier – x 1000)

DESCRIPTION	UNIT	OPTION "A"		OPTION "B"		OPTION "C"	
		QUANTITY	COST	QUANTITY	COST	QUANTITY	COST
SYSTEM DATA:							
ROUTE LENGTH	RF	7945	0	7945	0	7945	0
TRACK LENGTH	TF	15890	0	15890	0	15890	0
NUMBER OF STATIONS	EA	3	0	3	0	3	0
CONSTRUCTION COSTS:							
SITE MODIFICATIONS							
DEMOLITION	LS	4	4217	4	4083	4	4080
UTILITY RELOCATION	RF	7945	13135	7945	12083	7945	12039
STREET MODIFICATIONS	SY	6066	607	6066	607	6066	607
UNDERPINNING	LS	4	7875	4	7875	4	7875
GDWAY RETAINED CUT	RF	883	5783	883	5783	883	5783
SUB– CUT & COVER DBL BOX	RF	1212	@ 24,000/ft 29199	1212	29199	1212	29199
TUNNEL	RF	4050	17,000/ft 69936	4590	16,600 76250	4430	16600 73592
STATIONS SUBWAY							
CTR PLAT, W/ MEZZ	EA	1	36638	1	36638	1	36638
STACKED (W/TUNNEL)	EA	2	65150	2	59216	2	56284
JET GROUTING	LS	1	9069	1	9069	1	9069
Subtotal CONSTRUCTION COSTS:			$241,609		$240,803		$235,166
CONTINGENCY			72,483		72,241		70,550
TOTAL CONSTRUCTION COSTS:			$314,092		$313,044		$305,716
OTHER COSTS TO THE CITY:							
HOTEL STREET MALL	SF	119050	8833	119164	8833	119230	8833
LANDSCAPING	LS	1	1346	1	1108	1	1099
STATION FINISHES	LS	1	17500	1	17500	1	17500
PRIVATE UTILITIES	LS	1	3941	1	3625	1	3612
RIGHT OF WAY & AGREEMENTS	LS	1	70734	1	68754	1	53544
Subtotal OTHER COSTS TO THE CITY:			$102,354		$99,820		$84,588
CONTINGENCY			30706		29946		25376
TOTAL OTHER COSTS TO THE CITY:			$133,060		$129,766		$109,964
TOTAL CONSTR & OTHER COSTS			$447,152		$442,810		$415,680
ENGR & MGMT (GEC + OWNER COST)			44715		44281		41568
ESCALATION:							
ESCALATION			0		0		0
PROJECT RESERVE:							
PROJECT RESERVE			0		0		0
TOTAL:			$491,867		$487,091		$457,248

FILE: H:\LOTUS\HOTEL–ST.WK3


Hotel St.
GUIDEWAY
Maunakea St.
DN
MENDONCA
BUILDING
Smith St.
DN

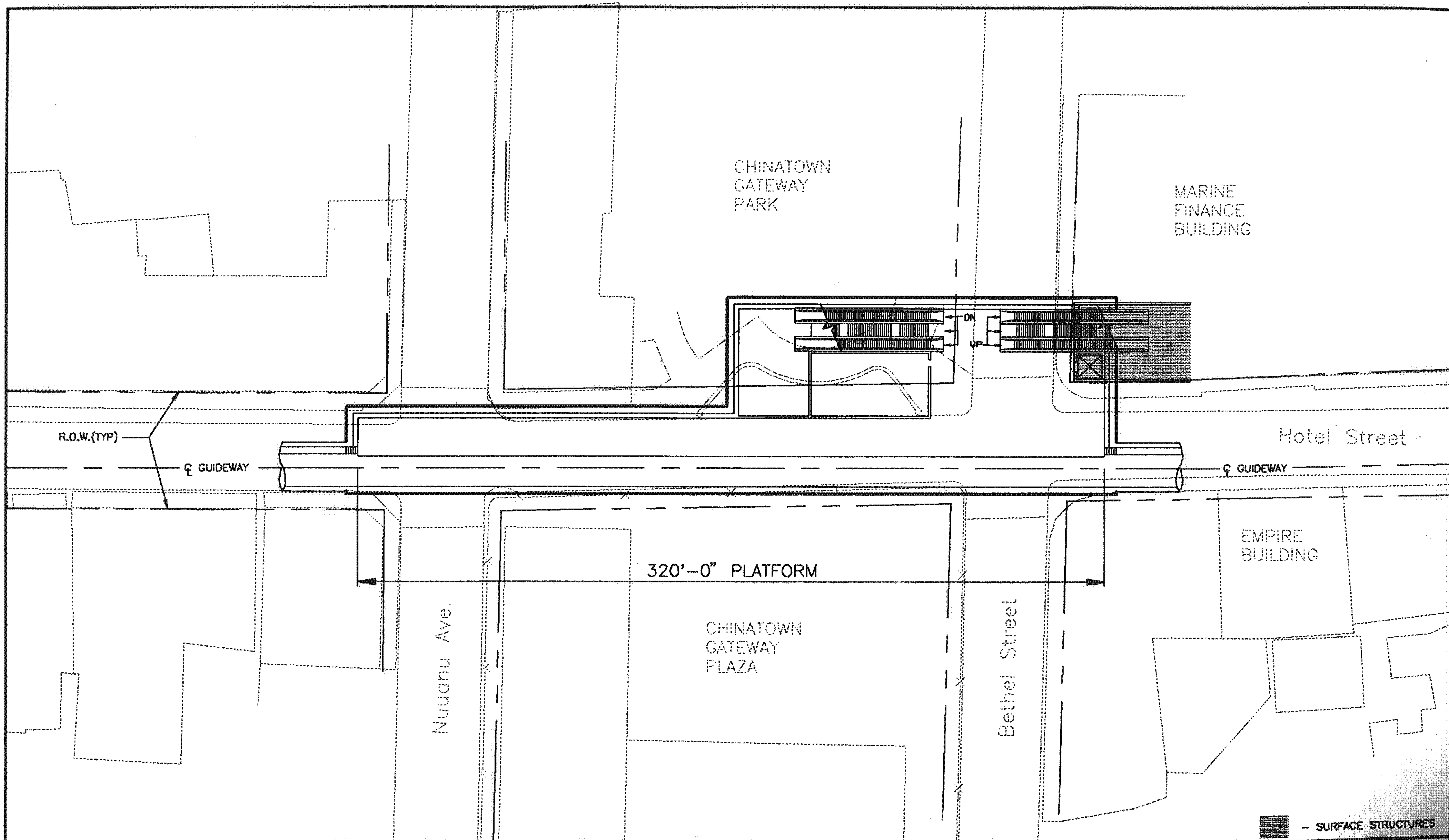


GRAPHIC SCALE

40 0 40 80

HOTEL/BETHEL STATION OPTION "A"

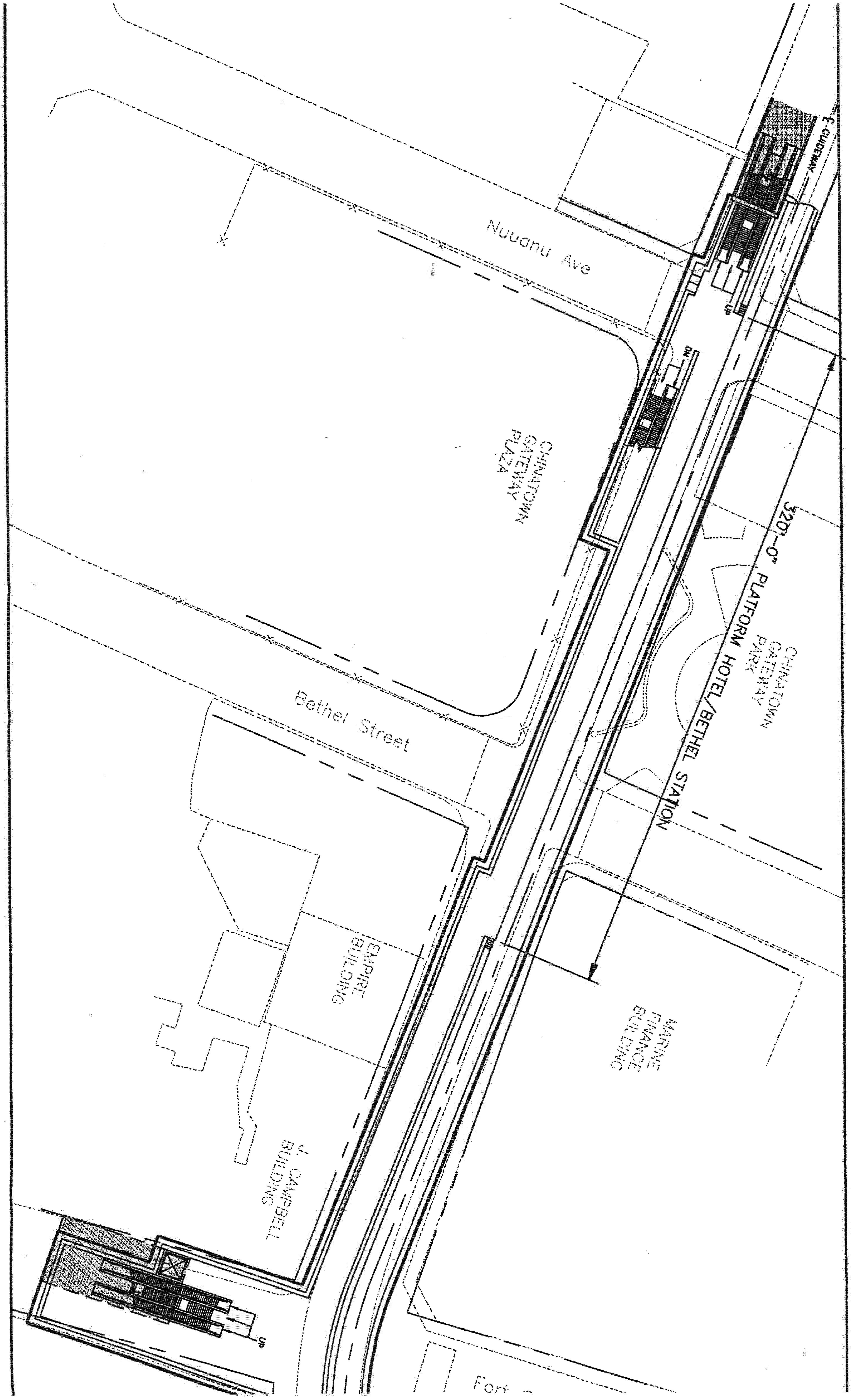
SKETCH 7.1

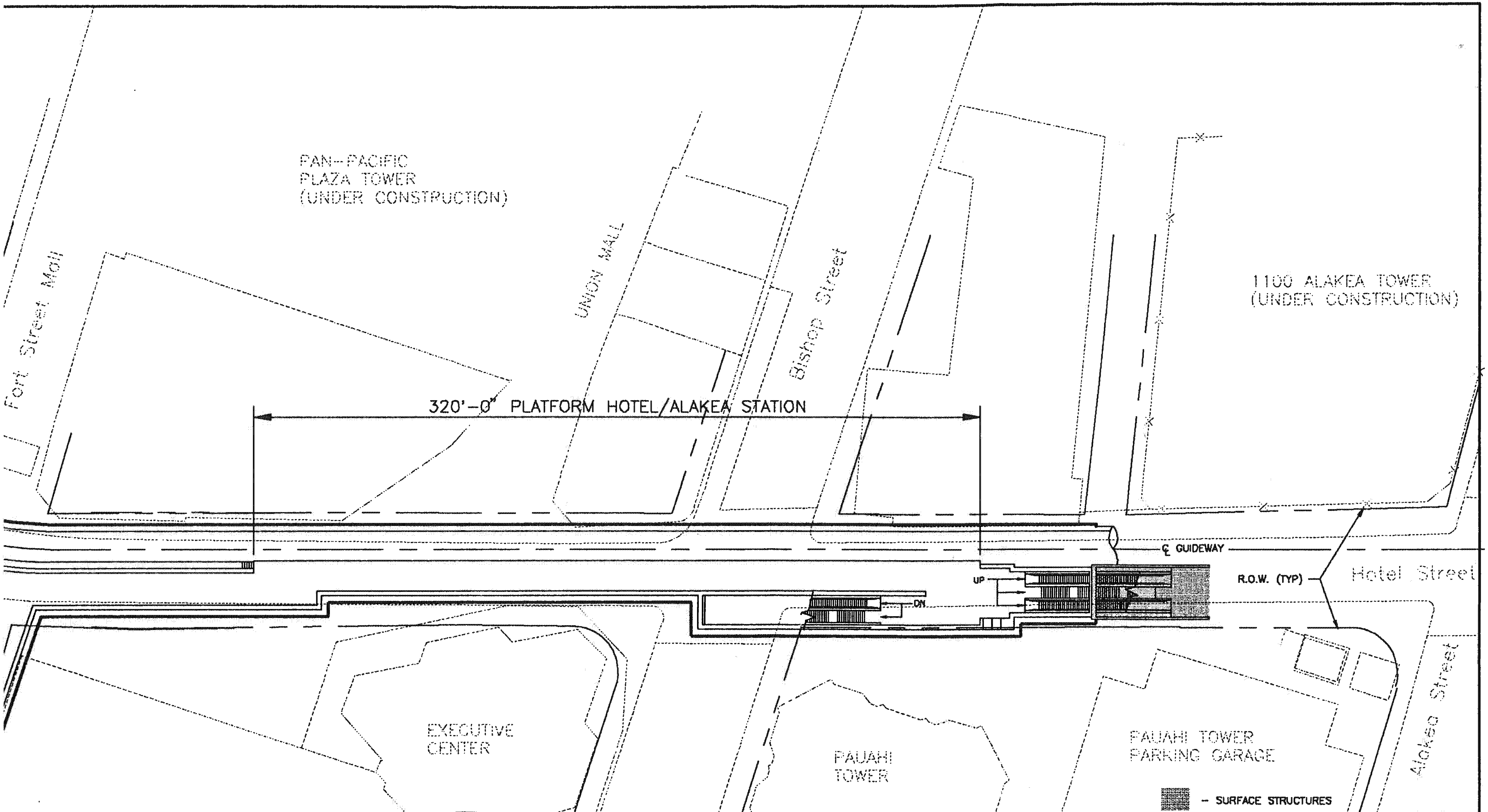


HOTEL/BETHEL STATION OPTION "B"

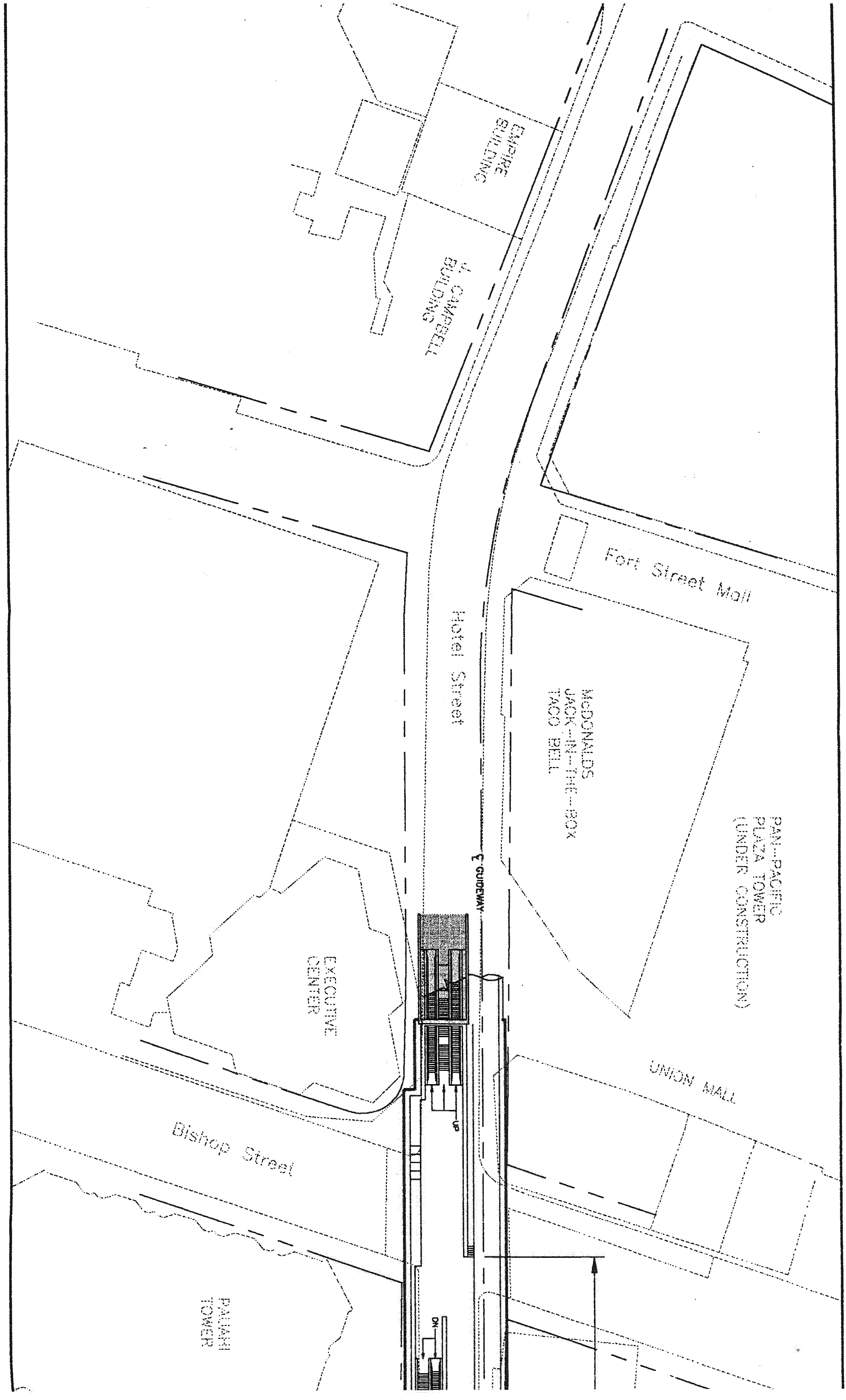
SKETCH 7.2

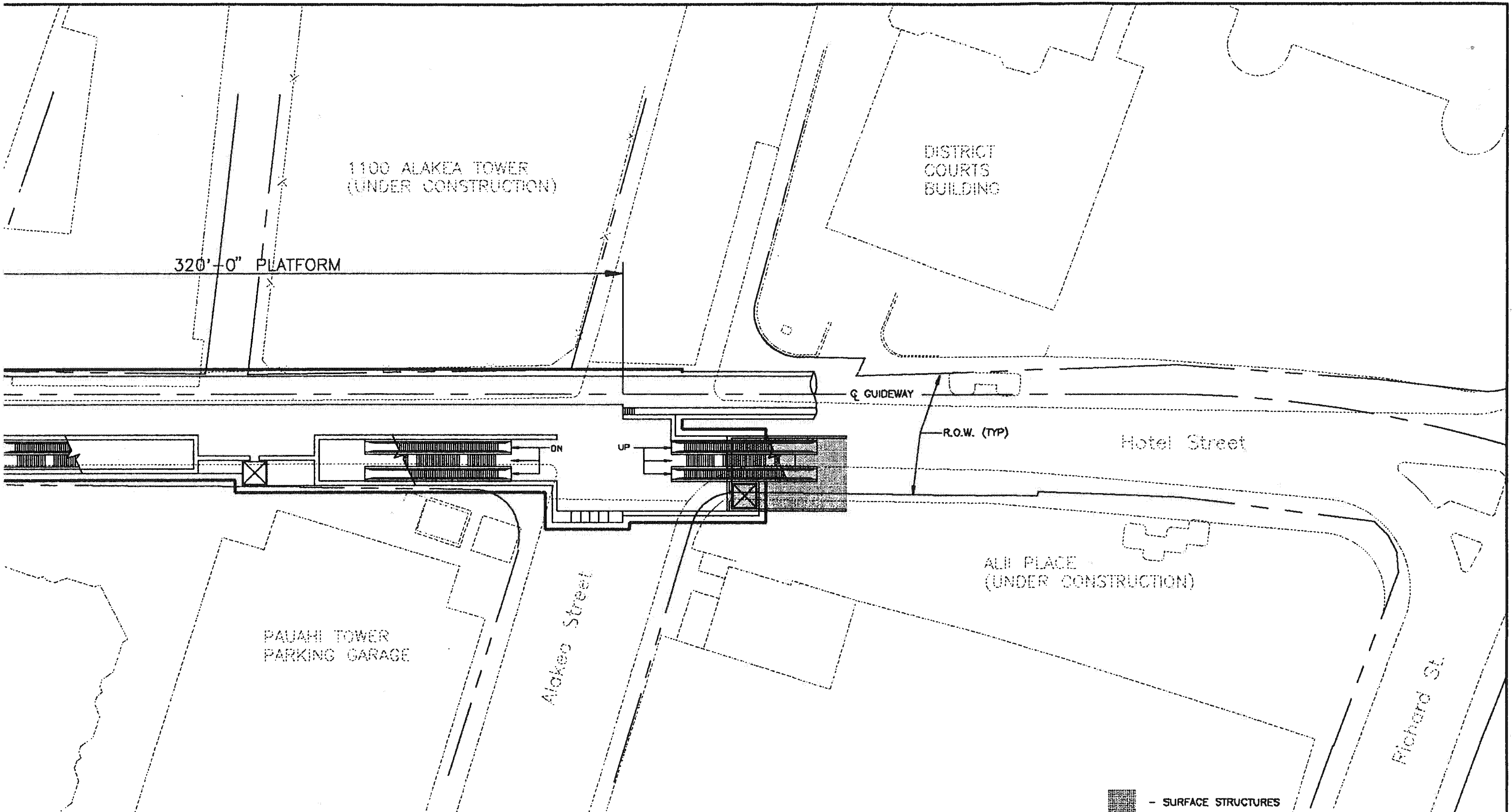
HOTEL\HB-B


Nuuanu Ave
GUIDEWAY
UP
DN
CHINATOWN GATEWAY PLAZA
320'-0" PLATFORM HOTEL/BETHEL STATION
CHINATOWN GATEWAY PARK
Bethel Street
EMPIRE BUILDING
MARINE FINANCE BUILDING
J. CAMPBELL BUILDING
UP



GRAPHIC SCALE 40 0 40 80	HOTEL STREET STATIONS OPTION "C"	SKETCH 7.3


EMPIRE BUILDING
J. CAMPBELL BUILDING
Fort Street Mall
Hotel Street
McDONALDS
JACK-IN-THE-BOX
TACO BELL
PAN-PACIFIC PLAZA TOWER (UNDER CONSTRUCTION)
℄ GUIDEWAY
EXECUTIVE CENTER
UNION MALL
UP
Bishop Street
PAUAHI TOWER
DN

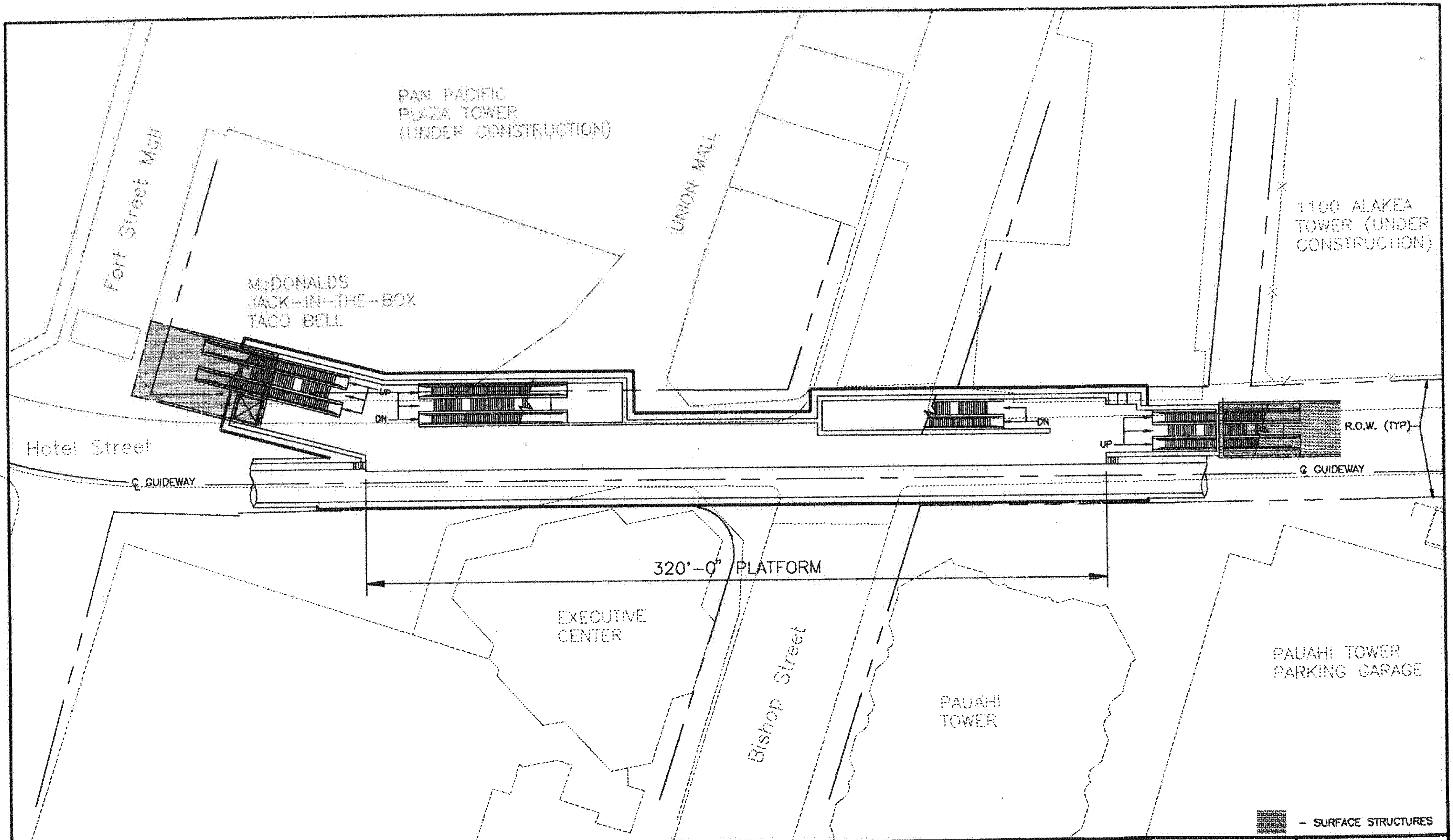


GRAPHIC SCALE

40 0 40 80

HOTEL/ALAKEA STATION OPTION "A"

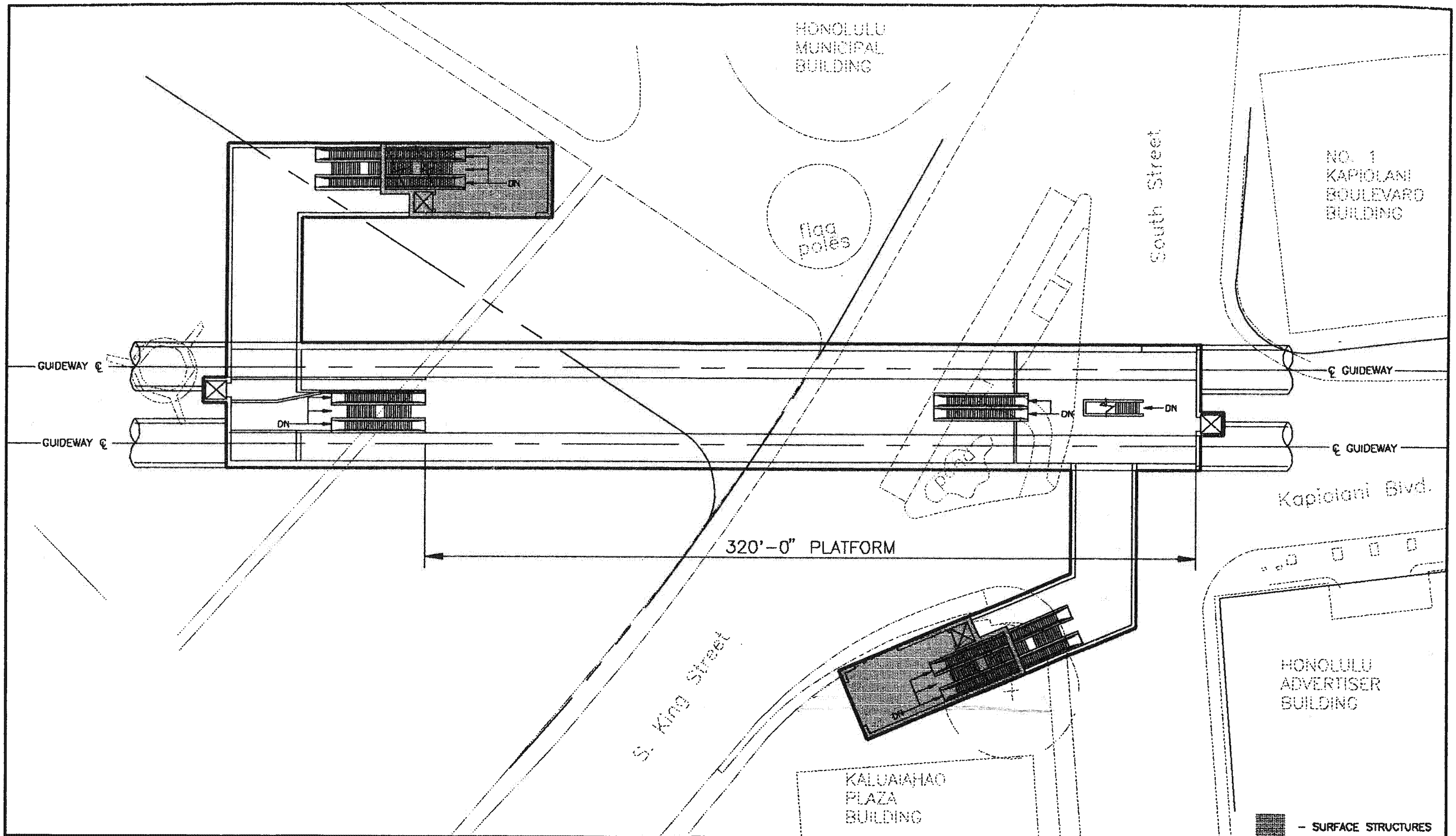
SKETCH 7.4



GRAPHIC SCALE
40 0 40 80

HOTEL/ALAKEA STATION OPTION "B"

SKETCH 7.5



CIVIC CENTER STATION OPTION "A"

SKETCH 7.6

8. SUMMARY OF OPTIONS

8.1 Introduction

An evaluation summary of the three subway options "A," "B," and "C," has been prepared that concludes the alternative scenarios discussed in Section 7 and concisely presents the relevant characteristics of each scheme. The ensuing evaluation matrix addresses six primary categories that are subdivided into specific divisions of distinct attributes. The evaluation matrix is only a relative gauge that measures the characteristic performance of the three subway options against the defined categories.

There are no relative weights assigned to the selected evaluation categories. Obviously, some categories are of much greater significance than others. The significance, or weight of importance, is very much a variable dependent upon the perspective of the influenced individual. Some evaluation categories have no relative distinctions when assessed against the three subway options. They are included for completeness, and where appropriate, a dashed line (--) is used to denote "no distinction."

8.2 Evaluation Matrix

EVALUATION CATEGORY	OPTION "A"	OPTION "B"	OPTION "C"
1.0 RIDERSHIP, USER COMFORT, AND CONVENIENCE			
1.1 Station Accessibility	Good	Fair	Good
1.2 Orientation in Station	Good	Good	Good
1.3 Bus Transfer Potential	Good	Fair	Good
2.0 CONSTRUCTION IMPACT			
2.1 R.O.W. Requirements			
- Businesses Displacement	51	66	26
- Residential Units Displacement	0	0	0
- Historic Properties Taken	0	0	0
- Parkland/Open Space Taken	0	0	1
- Parkland Construction Easement	0	1	0
- Street R.O.W. Taken	Moderate	Minimum	Moderate
- Temporary Business Disruption	16±	13±	18±
- Utility Relocations	Maximum	Minimum	Moderate
2.2 Traffic Disruptions			
Sidewalk	Moderate	Minimum	Moderate
Street	Moderate	Minimum	Moderate
Construction Traffic	--	--	--
2.3 Construction Noise	Moderate	Minimum	Moderate
2.4 Visual Impact	--	--	--

EVALUATION CATEGORY	OPTION "A"	OPTION "B"	OPTION "C"
3.0 CONSTRUCTABILITY			
3.1 Construction Duration - Tunnels	2 years	2 years	2 years
3.2 Construction Duration - Stations	2-1/2 years	2-1/2 years	2-1/2 years
3.3 Building Protection	--	--	--
3.4 Safety - General Public	--	--	--
3.5 Safety - Contractor's Forces	--	--	--
4.0 LONG TERM IMPACTS			
4.1 Traffic			
- Pedestrian	Good	Fair	Fair
- Automobile	Good	Good	Good
- Bus	Good	Fair	Good
4.2 Noise and Vibration	--	--	--
4.3 Aesthetics			
- Surface Features	Good	Good	Fair
- Station Interiors	--	--	--
4.4 Safety and Security	Fair	Good	Poor
4.5 Property Values	Good	Good	Good
5.0 TRANSIT OPERATIONS			
5.1 Operational Flexibility	Good	Good	Good
5.2 Station Functionality	Good	Good	Good
5.3 Station Expandability	--	--	--
5.4 Evacuation Characteristics	Good	Good	Fair
5.5 Maintainability	Fair	Good	Fair

EVALUATION CATEGORY	OPTION "A"	OPTION "B"	OPTION "C"
6.0 COST AND FINANCE			
6.1 Construction Cost (millions)	$492	$487	$457
6.2 Operating Cost	Fair	Good	Fair
6.3 Joint Development Potential	Good	Good	Fair

9. RECOMMENDATION

The evaluation matrix that summarizes the three subway options indicates that each alternative possesses relative advantages and disadvantages, corresponding to specific evaluation categories. From an overall perspective, none of the subway options was found to have a distinct advantage. In terms of ridership, Options "A" and "C" were rated superior to "B." Option "B" appeared to be superior in terms of construction impact and transit operations, while Option "A" surpassed the alternatives for the evaluation of long-term impacts.

The lowest construction cost was associated with Option "C." However, when considered in conjunction with operating cost and potential for joint development, the best choice is not clearly defined. In addition, the variation of estimated construction cost between the three options is $35 million, which is less than the average estimate contingency of $100 million. Consequently, the range of construction cost exceeds the level of estimating precision, and evaluation of cost criteria becomes nonconclusive.

Option "A" was selected as the solution for the Hotel Street Subway, primarily for the location of station entrances, ridership, and potential for joint development. The probable joint development opportunities identified for Option "A" would also simplify the vertical circulation elements at each entrance location. This is considered highly beneficial as it would eliminate the vertical circulation elements that are presently located within the station platform areas.